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A perceptual load theory framework of eating behaviour

Jenny Olivia Morris

Thesis submitted for the degree of Doctor of Philosophy

School of Psychology

University of Sussex

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Declaration

I hereby declare that this thesis has not been and will not be, submitted in whole or in part to another University for the award of any other degree.

Signature:

J. O. Morris

Acknowledgements

Obviously a huge thank you to my two brilliant supervisors, Professor Martin Yeomans and Dr Sophie Forster. I couldn't have asked for two more inspiring, fun and supportive people to guide me through this experience. Thank you to all of my fellow lab and office mates over the last three years, but particularly 'The J's', Jes, Jo and Jukka – our writing club and coffee breaks helped keep me motivated and sane (mostly!). Thank you to the people who've helped with the running of my experiments – especially Rhiannon, Keefe and Jordan – and to all those who participated. Last but not least, thank you to all the amazing family and friends who've put up with nerdy academic conversations for the last three years – although I can't promise they'll ever stop.

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Summary

A wealth of perceptual load theory research has suggested that different types of attentional demand can have opposite effects on perceptual processing: high perceptual demand reduces such processing whereas high cognitive demand increases it. However, this distinction has not been made within the eating behaviour literature. This thesis applied perceptual load theory to multiple aspects of eating behaviour. A series of behavioural studies tested whether processing of food-related cues and information related to consumption would also be reduced by manipulating the perceptual demand in a central task.

Papers one and two used established perceptual load paradigms to investigate external and internal processing of food-related cues. Paper one established that both attentional processing and recognition accuracy of external food stimuli were reduced by high perceptual load. There was tentative evidence that some individual differences (uncontrolled eating, hunger and body mass index) in the recognition accuracy of food stimuli persisted even under high perceptual load. Paper two found that high perceptual load also reduced appetitive-related thoughts. This effect was found across individuals, regardless of the number of appetitive-related thoughts reported under low perceptual load.

Papers three and four adapted the perceptual load task to allow simultaneous food consumption. Paper three found no evidence that high perceptual load reduced flavour awareness or influenced intake. Paper four found that participants were unable to respond to internal satiety signals when engaged in the high perceptual load task. This was reflected by failure to reduce intake and experienced satiety in response to consuming a high energy preload.

Overall, these studies have suggested that perceptual load theory is a valid framework for understanding eating behaviour. This has implications for both the eating behaviour and attention literatures. Most importantly, perceptual load theory could be used to predict the situations in which attention can be a help or a hindrance to appetite control.

Preface

The thesis conforms to article format with tables and figures embedded in the text. The four ‘article format’ empirical chapters are preceded by a general introduction chapter and followed by a general discussion chapter. A composite reference list is presented in APA style at the end of this thesis.

Paper 1 – under revision at *Journal of Experimental Psychology: General*

Paper 2 – under revision at *Appetite*

Paper 3 – written in the style of submission to *Appetite*

Paper 4 – submitted to *Appetite*

I have been the lead author on all papers regarding empirical work and writing. Professor Martin Yeomans and Dr Sophie Forster have supervised the empirical work and writing of this thesis. Their involvement is reflected in the order of authorship of the empirical chapters, with final author representing the principal investigator. Professor Martin Yeomans has provided feedback on paper three, the general introduction and general discussion. Professor Marianna Obrist and Dr Chi Thanh Vi provided equipment and technical assistance regarding the incorporation of TasteBud (an intra-oral infusion pump) into the design of Paper 4.

Some of the data in this thesis was collected by third year students for their undergraduate dissertations: the data for Experiment 1 in Paper 1 was collected by Jordan Neal and the data for Paper 2 was collected by Man Yung Keith Ngai. Rhiannon Armitage assisted in data collection for the experiment conducted in Paper 4.

1. General introduction

1.1. Overview and aims of the thesis

This thesis applies perceptual load theory of attention to eating behaviour. Selective attention is considered one of the earliest stages in perceptual processing and affects subsequent aspects of cognition such as memory (Lavie, 2005; 2010). The eating literature is comprised of large fields of research investigating attention at various stages of eating behaviour: from noticing the presence of food (and related cues) in our environment, to the point of consumption and the subsequent period where feelings of fullness tend to develop. The specific research relating to these areas will be outlined in more detail later in the thesis (Sections 1.3-1.4). These areas of research usually operate in isolation, and I argue there is a benefit to considering these effects as related phenomena. This thesis will utilise perceptual load theory of attention to provide a comprehensive framework linking these concepts together. Perceptual load theory is one of the most widely accepted theories of selective attention and predicts how and when stimuli in our complex sensory environment are selected for further processing. This thesis will use the understanding of basic perceptual processing, obtained via perceptual load theory, to explore a variety of eating-related behaviours. The theory will be fully outlined later in the thesis (Section 1.5), after the current literature on the role of attention in eating behaviour has been reviewed.

1.2. Cognitive approaches to eating behaviour

It is important to first outline how cognitive approaches to eating behaviour developed, as they have continued to shape subsequent research in the eating behaviour literature. Historical approaches to understanding appetite control focused on physiology

and homeostatic control. For example, it was suggested that individuals have a natural, biologically determined set point, and deviation from this set point (via changes in intake or expenditure) resulted in a negative feedback system that caused the individual to return to their original weight (Kennedy, 1953). However, the increase of obesity in recent decades raised awareness of environmental pressures on eating behaviour, such as accessibility to cheap, palatable and calorie dense food (often referred to an ‘obesogenic’ environment: Berthoud, 2004; de Castro & Plunkett, 2002; Martin & Davidson, 2014). The question of why some individuals struggle to control their appetite but others do not, despite environmental pressure, has emphasised the role of cognitive processing (the way an individual attends and reacts to food in their environment) in the control of eating behaviour (Werthmann, Jansen, & Roefs, 2015). There is now a wealth of research focusing on the role of cognitive processing in eating behaviour, and a variety of cognitive factors which exert an influence on eating behaviour have been identified, including attention, memory and executive control (for reviews see, Higgs, 2008, 2016; Higgs & Spetter, 2018; Jansen, Houben, & Roefs, 2015). This thesis will primarily focus on the role of attention, which I will argue has been a common aspect of several cognitive approaches to appetite control, including Externality theory and Restraint theory.

Some of the earliest experiments emphasising the role of cognitive processes in eating behaviour were conducted by Schachter (1968). These experiments led to Externality Theory, which argued that appetite control was dependent on the relative sensitivity to internal (e.g., feelings of fullness) and external (e.g., the sight and smell of food) food-related cues (Schachter & Rodin, 1974). One aspect of the theory was that over-reliance on external cues would result in overeating and obesity—although this aspect has since been

disputed (Reisenzein, 1983; Rodin, 1981) and healthy-weight individuals have also been shown to have high sensitivity to external food cues (Rodin & Slochower, 1976). The relationship between external cues and increased intake has been demonstrated in a variety of situations including time of day, exposure to visual and olfactory food cues, and the number and salience of food cues (Schachter, 1968; Schachter & Gross, 1968; Schachter & Rodin, 1974). Although an attentional mechanism was not explicitly tested in these studies, enhanced attentional processing of external stimuli was part of the theory's explanation as to why those high in external eating were hyper-responsive to external food cues. Recent research has supported this explanation by repeatedly finding that those scoring highly on external eating (as measured by the Dutch eating behaviour questionnaire, van Strien, Frijters, Bergers, & Defares, 1986) show enhanced attentional processing of visual food cues (Brignell, Griffiths, Bradley, & Mogg, 2009; Hou et al., 2011; Newman, O'Connor, & Conner, 2008; Nijs, Franken, & Muris, 2009; Nijs, Muris, Euser, & Franken, 2010). Therefore, the relationship between external cue reactivity and eating behaviour may be at least partly influenced by enhanced attention to those cues.

Related research has focused on Restraint Theory, which was developed to explain unsuccessful dieting. Early Restraint Theory argued that an eating style characterised by high cognitive control of intake resulted in reduced reliance on internal appetite-related cues (e.g., hunger and fullness) (Herman & Mack, 1975). In this sense Restraint Theory overlapped with Externality Theory and, like external eaters, restrained eaters also show increased attentional processing of external cues (Hollitt, Kemps, Tiggemann, Smeets, & Mills, 2010). Specific to Restraint Theory was the disinhibition effect, where disrupting restrained eater's cognitive control resulted in overeating. Herman & Mack (1975) tested

this aspect of the theory in the classic ‘preload’ design, where restrained eaters consumed more in a taste test after consuming a high energy milkshake (compared to no milkshake) and unrestrained eaters consumed less. The same effect was achieved by altering the perceived energy content (high or low calorie) of two identical preloads, further suggesting a role for cognitive processes in restraint (Spencer & Fremouw, 1979). Reduced self-monitoring has been suggested as a potential mechanism of the disinhibition effect. When participants were made more aware of their consumption (by leaving wrappers of consumed sweets on the table) or an experimenters judgement of their consumption (leaving the wrappers for the experimenter to collect), restrained eaters no longer displayed a disinhibition effect (Polivy, Herman, Hackett, and Kuleshnyk, 1986). The researchers suggested that manipulating the participants focus to the self and others was likely to have an attentional component, although other factors such as social norms regarding intake were also likely to have influenced the results. However, explicit manipulations of attention have also been shown to affect restrained eaters to a greater extent than unrestrained eaters. For example, restrained eaters consumed more snack food when engaged in a high cognitive load task (keeping numbers or images in short term memory) compared to a low cognitive load task (Ward & Mann, 2004; Mann & Ward, 2004). Similar to the pattern of results seen in the preload design, unrestrained eaters showed the opposite response and consumed less snack food when engaged in the high cognitive load task. These findings suggest that ‘disinhibition’ can occur as a result of a distraction task, which is likely to reduce attention available to control intake (potentially via the ‘reduced self-monitoring’ mechanism suggested by Herman & Mack, 1975).

The research outlined has highlighted the role of cognition in eating behaviour. In particular, Externality and Restraint Theory, which have shaped the literature for decades. While both theories relate to a wider role of cognition (e.g., self-control), the role of attention has been implicated in both the processing of food-related cues and consumption of food. This has highlighted that attention has a role in eating behaviour at multiple stages. The subsequent sections will detail the specific literature relating to attentional processes that occur before, during and after food consumption.

1.3. Role of attention in eating behaviour before food consumption

Selective attention allows us to prioritise certain environmental information while ignoring other less relevant information. How attention is allocated depends on a variety of mechanisms, which have fallen into two main categories: top down (goal driven) or bottom up (salience driven) (Connor, Egeth, & Yantis, 2004; Desimone & Duncan, 1995; Egeth & Yantis, 1997; Katsuki & Constantinidis, 2014). It should be noted that a strict top-down vs. bottom-up dichotomy has been disputed (Awh, Belopolsky, & Theeuwes, 2012), but it has nonetheless shaped the attention literature. Food stimuli have been shown to capture attention via both top-down and bottom-up mechanisms. For example, holding a food-related cue in working memory has been found to guide attention towards external food stimuli to a greater extent than non-food stimuli (Higgs, Rutter, Thomas, Naish, & Humphreys, 2012). However, successful dieters (defined by those high in restraint but low in disinhibition) showed reduced attention to external food compared to non-food stimuli, even when holding a food-related cue in working memory (Higgs, Dolmans, Humphreys, & Rutter, 2015). Therefore, both short term and long term top-down goals have been shown to influence attentional allocation to food stimuli. On the other hand, food is a highly

salient cue (due to its rewarding properties) that has been argued to capture attention in a bottom-up manner (Castellanos et al., 2009; Robinson & Berridge, 1993). Research has shown that in hungry individuals, food stimuli captured attention in an involuntary manner, even when it was detrimental to top-down goals (Piech, Pastorino & Zald, 2010). Recently, a third ‘value-driven’ mechanism has been integrated with top-down and bottom-up selection (Anderson, Laurent & Yantis, 2013; Anderson, 2016). This area of attention research has argued that stimuli can capture attention based on previous reward history, even when non-salient and task irrelevant. For example, after being associated with a chocolate odour in a classical conditioning paradigm, irrelevant shapes continued to capture attention when presented without the chocolate odour (Pool, Brosch, Delplanque, & Sander, 2014). This additional value-driven mechanism helps to explain how a variety of food-related cues capture attention.

The above research has highlighted the variety of ways that food (and related cues) can capture attention: food stimuli are highly salient, relevant to top-down goals and rewarding. Therefore, it is thought that food stimuli should receive enhanced attentional processing (usually defined as ‘attentional bias’, referring to the tendency for food stimuli to receive preferential attention above and beyond non-food stimuli) (Field & Cox, 2008; Werthmann et al., 2015). Furthermore, our obesogenic environment is full of cues signalling the presence of food such as direct sensory cues (sight, smell etc.) and food-related cues such as advertisements, meaning that a biased attentional system towards food presents an opportunity for those cues to influence eating behaviour (Martin & Davidson, 2014).

1.3.1. Theoretical approaches to attentional bias

The majority of theories explaining attentional bias have come from the addiction literature. The incentive sensitisation theory is one such influential model, which was originally conceived in regard to drug use, but has since been applied to food. Robinson & Berridge (2001) proposed that the sensitisation of the dopaminergic system increases the salience of reward-related cues (e.g., food), making them more likely to capture attention. The Incentive sensitisation theory (Robinson & Berridge, 2001) further suggests that salience may be increased by conditioned associations between cues and the rewarding effects of ingestion (e.g., sensory experience, post-ingestive effects of nutrients, etc). This conditioning process is thought to occur when repeated dopamine release accompanies the rewarding substance (consuming food). In turn, frequent simultaneous pairing of the rewarding substance and related cues (e.g., sight of food and food packaging) results in the conditioning of the food-related cues. According to the theory, once the reward-related cues capture attention, they cause craving for the substance and increase the likelihood of consumption—in support of this idea attentional bias towards food cues is related to increased craving and consumption (Nijs & Franken, 2012; Werthmann et al., 2011). In addition, attentional bias is greater in overweight compared to normal-weight individuals (Nijs & Franken, 2012; Nijs et al., 2010; Werthmann et al., 2011). Further research has found altered reward functioning in obese compared to normal-weight individuals (Burger & Stice, 2011; Stice, Spoor, Bohon, & Small, 2008; Wang et al., 2001). Attentional bias to food cues has also been linked to activity in reward-related brain regions (right opercular regions, left anterior cingulate cortex, left hippocampus left opercular regions) (Yokum, Ng, & Stice, 2011). Enhanced orientation and reallocation of attention to food stimuli was

also related to higher BMI. Moreover, it was found that BMI correlated positively with activation in brain regions related to attention and particularly food reward (anterior insula/ frontal operculum), during initial orientation and reallocation of attention to appetizing food images.

Incentive sensitisation theory has made a distinction between ‘wanting’ and ‘liking’ aspects of reward processing. ‘Wanting’ refers the incentive salience process described above (Berridge, Robinson, & Aldridge, 2009). Whereas ‘liking’ refers to the hedonic (pleasurable) experience of consuming food, usually related to the taste of palatable foods. Both ‘liking’ and ‘wanting’ are usually involved in the rewarding effects of food (Havermans, 2011). However, research has suggested that they have dissociable neural underpinnings and can occur independently (Berridge, 2009). Importantly, food ‘wanting’ can be disconnected from food ‘liking’. For example, dopamine depleted rats show normal ‘liking’ and ‘disliking’ for sucrose and quinine (Berridge & Robinson, 1998). Conversely, excess dopamine in rats results in increased ‘wanting’ without the associated ‘liking’ for sweet foods (Pecina, Cagniard, Berridge, Aldridge, & Zhuang, 2003; Tindell, Berridge, Zhang, Pecina, & Aldridge, 2005). The presence of substance-related cues usually correlates with increased ‘wanting’, referring to the motivation to obtain and consume the substance. Attentional bias is the cognitive consequence of the conditioning process and is thought to be more reflective of ‘wanting’ than ‘liking’ (Berridge et al., 2009).

The idea of substance-related cues capturing attention and resulting in over-consumption is common to several theories, which usually claim that the level of attentional bias should be closely related to craving (Appelhans, French, Pagoto, & Sherwood, 2016; Hofmann & Van Dillen, 2012). Theories such as the cognitive

psychopharmacological model (Franken, 2003), the elaboration intrusion (Kavanagh, Andrade, & May, 2005; May, Andrade, Kavanagh, & Hetherington, 2012) and dynamical models of desire (Hofmann & Van Dillen, 2012) expanded upon this idea, claiming that craving and attentional bias are the result of an underlying motivational process, and once triggered continue to cause interference until the food has been consumed or attention is redirected (e.g., through distraction).

Field & Cox (2008) developed an integrated theory of attentional bias, identifying common themes in the theories mentioned above. They described several key shared predictions. Firstly, once established through classical conditioning, attentional bias for substance cues (food included) is a stable characteristic. Food-related attentional bias should be most evident in people who are obese, as the association between reward and food should be stronger, but it should be present in all people to some extent (as exposure to food is essential to survival). Secondly, the extent of attentional bias in the individual should predict craving and consumption of the substance (likely demonstrated by weight gain in relation to food). Thirdly, attentional bias should have a causal influence on consumption (eating). And finally, attentional bias reflects an underlying appetitive motivational process, reflected by increased craving for the substance. There is now a wealth of attention bias research, which has supported the above predictions to a varying degree.

1.3.2. Evidence for attentional bias

In relation to food, attentional bias has been typically measured by cognitive tasks showing either faster identification of a food target (e.g. an image of a food item) or interference with a task when a food stimulus was presented as the distractor. The

attentional processing of the food stimulus is compared to that of a matched control stimulus; the difference between the two stimuli reflects the attentional bias. The Stroop task has been one of the most widely used indirect measures of food-related attentional bias. Participants are presented with words and asked to name the colour of the text while they ignore the word's semantic context. Food-biases are estimated by including trials where the word is the name of a rewarding food item, e.g. chocolate. Generally, participants are slower to name the colour of a food-related word compared to a non-food word (for a meta-analysis of studies in this area see, Johansson, Ghaderi, & Andersson, 2005). However, it has been suggested that indirect measures, such as the Stroop task, could also reflect an attempt to suppress attentional bias or a slowdown associated with experiencing food cravings (Field & Cox, 2008). More recently, direct assessment of attentional bias by measuring visuo-spatial attention have become more common. The dot probe (sometimes called visual probe) has been the most common visuo-spatial manipulation. In this task a food and non-food image appear simultaneously (one on the left and one on the right hand side of the screen) and the participant responds as quickly as possible to the probe stimulus (usually a dot) that appears after the images have disappeared. It should be noted that the images are task irrelevant and have no relation to the location of the probe stimulus. Participants should respond faster when the probe appears in the same location as the food image compared to the non-food image, indicating that their attention was already allocated to this location. Similar to the dot probe task, the exogenous cueing paradigm requires participants to respond to a probe, but only one stimulus image is presented on each trial.

Over the last three to four decades, a wealth of research has been conducted and several comprehensive reviews have investigated attentional bias to food stimuli (see, Doolan, Breslin, Hanna, & Gallagher, 2015; Field & Cox, 2008; Hendrikse et al., 2015; Nijs & Franken, 2012; Werthmann et al., 2015). However, well-designed studies do not always find evidence of bias for food cues. A likely explanation for this inconsistency is that attentional bias to food may be moderated by both the conditions under which participants are tested and individual differences in sensitivity to food as a reward. Theories of motivation further suggest that the extent to which we attend to such cues should depend on current need state (Denton, 2005): thus greater attentional bias for foods should be stronger when hungry than when sated. However, the literature on the effects of hunger state on attentional bias to food cues is also mixed: some studies report greater attention to food cues when participants were hungry (Castellanos et al., 2009; Tapper, Pothos, & Lawrence, 2010), but others have failed to find any such effect of hunger state (Hou et al., 2011; Loeber et al., 2012).

In relation to individual difference measures that are associated with variation in attentional bias, the literature to date also has many inconsistencies. In general, food attentional bias has tended to be stronger in individuals susceptible to overeating, such as those who are overweight (Hendrikse et al., 2015; Werthmann et al., 2011), restrained eaters, defined as people with a tendency towards dieting, (Hollitt, Kemps, Tiggemann, Smeets, & Mills, 2010), people with a tendency towards uncontrolled eating (disinhibited eaters: Seage & Lee, 2017) and individuals with greater sensitivity to external food cues (external eaters: Brignell, Griffiths, Bradley, & Mogg, 2009; Hou et al., 2011). However, these relationships have not proved reliable. For example, Nijs, Muris, Euser & Franken

(2010) only found evidence for effects of external eating using EEG measures but not using more direct measures of attention to food cues. Others have failed to find relationships between restraint and attentional bias (Ahern, Field, Yokum, Bohon, & Stice, 2010; Boon, Vogelzang, & Jansen, 2000; Freijy, Mullan, & Sharpe, 2014), while Werthmann et al., (2013) found attentional bias was independent of restraint when controlling for BMI. Likewise, several studies have failed to find food attentional in obese populations (Loeber et al., 2012), or related to BMI on behavioural measures (Tapper et al., 2010; Werthmann et al., 2011), leading a recent review to conclude that the relationship between food cue sensitivity and obesity remains unclear (Doolan et al., 2015). Many of the individual difference factors associated with eating are also related to broader personality measures, most notably impulsivity. Although impulsivity itself is a multi-faceted construct (Meule, 2013), in the present context it is notable that some studies have found correlations between measures of impulsivity and attentional bias to food cues. For example, scores on the Barratt Impulsiveness Scale were related to food attentional bias in multiple studies (Hou et al., 2011; Lattimore & Mead, 2015; Meule & Platte, 2016). However, there have been notably fewer studies examining impulsivity as a predictor of food attentional bias, and the range of measures of impulsivity used in studies to date have been limited.

1.3.3. Contribution of attentional bias to consumption

One of the key theoretical predictions regarding attentional bias is that it impacts subsequent intake. Indirect evidence for this prediction comes from research which has found that attentional bias for food cues has been frequently associated with higher BMI (Castellanos et al., 2009; Nijs et al., 2010; Nummenmaa, Hietanen, Calvo, & Hyönä, 2011; Werthmann et al., 2011; Yokum et al., 2011). More direct evidence has found that

attentional bias, measured by ERP, was associated with subsequent food intake in a bogus taste test (Nijs et al., 2010). The bogus taste test is a widely used method to measure intake (Robinson et al., 2017). Typically, the participant is left alone for a short period (e.g., five to ten minutes) with one or more food items. To disguise the purpose of the test, the participant is asked to make taste ratings about the food (which are usually discarded), while the experimenter unobtrusively measures intake (e.g., by weighing the food before and after the experiment). However, the relationship between attentional bias and consumption was found in overweight individuals only (Nijs et al., 2010). Subsequent research, also using a bogus taste test, found that although overweight individuals consumed more food, this was not associated with eye tracking or behavioural measures of attentional bias (Werthmann et al., 2011). Instead, initial orientation direction bias towards high-fat food stimuli was positively associated with subjective craving, in normal-weight participants only. The difference between these studies could be explained by ERP and eye tracking measures tapping into different aspects of attentional bias in different groups. Nevertheless, both studies found a link between attentional bias and eating-related behaviours.

The contribution of attentional bias towards overeating has also been investigated by manipulating the bias. Werthmann, Field, Roefs, Nederkoorn, & Jansen (2014) found that instructing participants to attend to chocolate images during an attention bias modification task (an antisaccade task, where participants directed their gaze towards the instructed stimuli) resulted in them consuming more chocolate after the task than participants who had attended to non-food images. In contrast, Kakoschke, Kemps, & Tiggemann (2014) trained participants to attend healthy food cues using a modified version

of the dot-probe task, where healthy food images were followed by the dot-probe on 90% of trials (usually there is no relation between the image and location of the dot). Participants showed increased attentional bias for and consumption of healthy snacks compared to participants who attended unhealthy food cues. More recently, Stice, Yokum, Veling, Kemps, & Lawrence (2017) used multiple attention retraining tasks—participants completed five tasks once a week for four weeks. Three of tasks (stop-signal, go/no-go and respond-signal training) involved participants making a task response depending on a simultaneous neutral-non-food cue (blue or grey image frame, dashed or non-dashed image frame, a noise or no noise signal), which was consistently paired with either healthy or unhealthy food images. Participants withheld their response when the neutral cue was associated with unhealthy food images and made a response when the neutral cue was associated with healthy food images. The fourth task was a modified dot-probe task, where the probe appeared after a healthy image on 90% of trials and after a unhealthy image on 10% of trials. The final task was a visual-search display, where participants searched for one healthy food image among multiple unhealthy food images. Compared to a control group (who underwent the same retraining procedure with non-food images), those in the food attentional retraining condition showed reductions in responsiveness of neural regions associated with attention (inferior parietal lobe) and reward (putamen and mid insula) when viewing high calorie food images, reduced palatability ratings and monetary valuation of high calorie foods and body fat loss at the end of the trial. However, not all studies have demonstrated an effect of attentional bias manipulations on subsequent behaviour.

Hardman, Rogers, Etchells, Houstoun, & Munafò (2013) also used a visual probe task to train participants to either attend to or avoid images of cake. A third group received a no training control task. There was no effect of either training condition on hunger or food

intake, raising the possibility that attentional bias is more difficult to modify than the previously described studies suggest, particularly when using single session tasks. Multifaceted approaches like the one used by Stice et al., (2017) are likely to be most effective.

1.3.4. Intrusive thoughts

Another area of research, closely aligned with biased attention towards food cues, is that regarding food-related thoughts. We can also be distracted by internal thoughts, independent from the external environment. Within the attention literature, this has been referred to as mind wandering or task unrelated thoughts, often interchangeably (Forster, 2013; Seli, Cheyne, Xu, Purdon, & Smilek, 2015; Smallwood & Schooler, 2015), and has typically been measured with a probe-caught method where the participant reports whether they have experienced a task unrelated thought in response to a probe question. For example, McVay and Kane (2009) tested participants on a sustained attention task, which involved responding to whether a word that appeared on-screen was lower or upper case. However, participants had to make or withhold their response depending on the word category (animal: make response; food: withhold response). On 7% of trials, participants answered a probe-question ‘What were you just thinking about?’ and were given seven response options. Research has estimated between 30-50% of waking cognition is accounted for by task unrelated thoughts (Killingsworth & Gilbert, 2010; Klinger & Cox, 1987; McVay et al., 2009). Hofmann, Baumeister, Förster, & Vohs (2012) used experience sampling (which required participants to respond to probe questions throughout the day) to investigate the type of desires people experience: eating was the most frequently reported desire (28.1%), followed by sleeping (10.3%) and drinking (8.6%). Their findings suggest

that people thought about food frequently, however, it's unclear when and under what circumstances these thoughts occurred.

Within the eating behaviour literature, intrusive thoughts have usually been considered in the context of craving. The link between craving and consumption has been well documented (Delahanty, Meigs, Hayden, Williamson, & Nathan, 2002; Hetherington & Macdiarmid, 1995; Meule, Westenhöfer, & Kübler, 2011; Rodin, Mancuso, Granger, & Nelbach, 1991; Waters, Hill, & Waller, 2001), but less research has focused directly on food-related intrusive thoughts. In theories of addiction, intrusive food-related thoughts are considered a crucial initial trigger in a craving episode (Kavanagh et al., 2005; May et al., 2012). Often intrusive thoughts can be in response to food cues in the environment but have also been reported to occur spontaneously. Theories suggest that intrusive thoughts then contribute towards craving via their mutually excitatory relationship with attentional bias, meaning that an increase of craving (of which intrusive thoughts are a central element) results in an increase in the attention-grabbing ability of the food cues, which in turn increases attentional bias to the food cues, which then strengthens the experience of the craving (Field & Cox, 2008).

A line of research focusing on the role of working memory also suggests that intrusive thoughts may contribute to overeating via a reinforcing cycle between the thoughts and increased attention to food cues (Higgs, 2016). This means holding food-related information in working memory (food-related thoughts) will drive attention towards external food cues. In support of this idea, participants show increased food-related attentional bias after being asked to memorise a food image (a manipulation intended to increase food-related thoughts) (Higgs, Robinson, & Lee, 2012). External attention to food-

related cues then further stimulates food-related thoughts. In support of this idea, priming participants with food related words (via a lexical decision task where participants judge whether presented words are real words or nonwords, and 1/3 of the real words were food-related) strongly correlated with frequency of self-reported food-related thoughts (via a questionnaire; Berry, Andrade, & May, 2007). It's thought that the reinforcing cycle allows food stimuli to receive elaboration in working memory, which underlies craving (Higgs, 2016). This prediction is supported by studies showing that tasks which tax working memory reduce food craving (e.g., Kemps, Tiggemann, Woods, & Soekov, 2004). Furthermore, this line of research also allows for the role of individual differences, by suggesting that increased accessibility of food-related thoughts (e.g., due to previous memories) will increase the likelihood of that thought receiving further processing in working memory (Higgs, 2016). In support of this, the majority of studies looking at food-related thoughts have found that they are increased under conditions of hunger (Berry et al., 2007), dieting (Kemps & Tiggemann, 2005), and in those with higher BMI (Israel, Stolmaker, & Andrian, 1985).

Recently, research has highlighted that the effect of intrusive food-related thoughts is supported by the associated mental imagery. Kemps & Tiggemann (2005; 2007) have suggested that a mental imagery task can be successfully used to reduce food-related thoughts and craving because they both rely on the same cognitive resources. They argue that visual and olfactory imagery tasks should be most effective, as these sensory modalities are more strongly activated in response to food-related thoughts and cravings. Several studies have used external visual imagery tasks, such as self-generated imagery, dynamic visual noise, constructing clay shapes, playing Tetris and making hand movements

to reduce food cravings (for review see, Kemps & Tiggemann, 2015). However, very few studies have directly reduced food-related thoughts, with the exception of May, Andrade, Batey, Berry & Kavanagh (2010). They used a probe based method to monitor thoughts at 20 intervals during a 10 minute period. Food-related thoughts were reduced by self-directed and guided visual imagery compared to a baseline 10 minute control period. Therefore, this study indicated that visual imagery could prevent the generation of the food-related thoughts suggested to underlie cravings. As intrusive thoughts underlie one of the earliest aspects of craving, they may be especially useful to target before the thought receives further processing.

Visual imagery tasks are an improvement over previous craving reduction methods. For example, thought suppression (actively trying not to think about food), was found to be at best ineffective and at worst resulted in a counter-productive rebound effect, where food cravings and/or thoughts are increased (Barnes, Masheb, & Grilo, 2011; Erskine, 2008; Erskine & Georgiou, 2010; Hooper, Sandoz, Ashton, Clarke, & McHugh, 2012; Johnston, Bulik, & Anstiss, 1999; Soetens, Braet, Dejonckheere, & Roets, 2006). However, an issue with using a visual imagery task to reduce food-related thoughts and/or craving is that it relies on the individual and is therefore not always an accessible strategy. For example, people vary in the creativeness and strength of imagery they can generate (Cui, Jeter, Yang, Montague, & Eagleman, 2007) and, in the extreme example of aphantasia, some individuals cannot generate any visual imagery (Keogh & Pearson, 2018). In addition, while it may be possible to use visual imagery strategies when not engaged in a task (e.g., sitting on a bus) it is likely to be difficult when attempting to concentrate on a work related task (and the strategy may interfere in the primary task).

1.3.5. Summary: the role of attention before food consumption

To summarise, the role of attention in processing external food cues has been extensively researched. A summary of current opinion is that food cues become salient through classical conditioning, which increases their ability to capture attention. Over time, attentional bias for those cues develops. Attentional bias then contributes towards consumption via a mutually excitatory relationship with craving. Internal food-related thoughts have been studied to a lesser extent, however, they are seen as a crucial aspect of craving. Food-related thoughts have been suggested to be involved in the triggering and maintenance of a craving episode and can either occur as a response to external food cues or potentially spontaneously. Given the hypothesised relationship between attention to food and intake, several attempts have been made to modify attention. However, research attempting to alter attentional bias has proved inconclusive—some studies have claimed that attentional bias is a difficult to alter, stable trait. Promisingly, visual imagery tasks have been shown to reduce subjective craving. And, one study also found self-guided imagery specifically reduced food-related thoughts. However, this method relied on having the task available and depending on the task may be cognitively effortful. Currently, theoretical approaches allow for differences in attention towards food cues in certain individuals and in certain situations (e.g., when the individual is hungry). However, there is little role for how basic attentional processes might control the ability of food to capture attention. Later in the thesis, I will outline how attention to food might be dependent on basic perceptual limits. I will also suggest how this understanding might be used to reduce attention to food automatically, and potentially the associated consumption.

1.4. Role of attention in eating behaviour during food consumption

Inattentive eating has become a growing issue in our modern obesogenic environment. While attention to food cues before consumption generally has negative effect in terms of increasing likelihood of overeating, the opposite is true during consumption. Disrupting attention with a cognitive task such as television or video games increases both immediate and subsequent consumption (for review see, Robinson et al., 2013). Television has been most commonly used as a naturalistic distraction task in studies looking at inattentive eating. Typically, studies have compared food intake while participants watched television with intake without television. Many studies have now found that eating with television increases intake (Bellisle & Dalix, 2001; Bellissimo, Pencharz, Thomas, & Anderson, 2007; Blass et al., 2006; Braude & Stevenson, 2014; Chaput, Klingenberg, Astrup, & Sjödin, 2011; Hetherington, Anderson, Norton, & Newson, 2006; Martin, Coulon, Markward, Greenway, & Anton, 2008; Ogden et al., 2013; Temple, Giacomelli, Kent, Roemmich, & Epstein, 2007). Increased intake has also been found in studies using audio stories (Bellisle & Dalix, 2001; Long, Meyer, Leung, & Wallis, 2011), music (Chaput et al., 2011; Stroebele & de Castro, 2006) and computer/video games (Chaput et al., 2011; Oldham-Cooper, Hardman, Nicoll, Rogers, & Brunstrom, 2010). Regardless of the task used, all these studies involved a method that diverted attention away from food, suggesting that attention has a key role in controlling eating behaviour. However, as will be discussed in the following sections, the mechanisms of this increased intake are not well understood due to the complex nature of eating behaviour.

1.4.1. Theoretical approaches to inattentive eating

Theoretical approaches to inattentive eating have been rooted in Restraint Theory (Herman & Mack, 1975) and the closely related Boundary Model (Herman & Polivy, 1984). The latter integrated the ideas of Restraint Theory with wider understanding of eating regulation. The theory proposes that food intake is controlled by the physiological boundaries of hunger at one end and satiety and the other. In-between these boundaries lies a ‘zone of biological indifference’ where intake is determined by a variety of non-homeostatic environmental factors. However, restrained eaters rely on a self-imposed cognitive diet boundary to control their intake; and because this boundary comes before their natural satiety boundary, it is cognitively difficult to maintain. Attention is one cognitive mechanism likely to be involved in maintenance of dieting goals (Polivy, Herman, Hackett, & Kuleshnyk, 1986; Ruderman, 1986; Stroebe et al., 2017), however, other related mechanisms such as memory have also been heavily implicated (Higgs, Robinson & Lee, 2012; Higgs & Spetter, 2018; Martin & Davidson, 2014). Distraction tasks are thought to reduce attention to the eating experience, including the maintenance of dieting goals (Mann & Ward, 2004; Ward & Mann, 2000). Therefore, in the context of Restraint and Boundary theory, distraction tasks are likely to overload cognitive resources and result in a transgression of the diet boundary. Once the diet boundary has been broken, dieting goals are ignored and ‘disinhibition’ occurs.

1.4.2. Effects of distraction on restrained eaters

In support of Restraint Theory and the boundary model, research has found that restrained eaters are more susceptible to inattentive eating when compared to unrestrained eaters. Ward & Mann (2000) gave participants access to high calorie food while they

completed a simple reaction time task (responding to a beep which sounded periodically), but participants assigned to the distraction condition were additionally instructed to simultaneously memorise a series of images (artistic paintings) in preparation for a memory test. Restrained eaters consumed significantly more food in the distraction condition compared to the no distraction condition. Unrestrained eaters showed the opposite effect. A similar study was conducted with restrained eaters only, who were given a milkshake to taste while remembering a one digit (no distraction) or nine digit (distraction) number to remember (Mann & Ward, 2004). Again, consumption was higher in the distraction condition compared to the no distraction condition — although this effect was eliminated when dieting goals were made salient by asking participants to complete the restraint scale (Dutch eating behaviour questionnaire version) before the experiment. The authors in both studies (Ward & Mann, 2000; Mann & Ward, 2004) concluded that the task distracted participants away from monitoring their dieting goals. Other researchers have also argued that maintenance of dieting goals requires attention (Hofmann, Gschwendner, Friese, Wiers & Schmitt, 2008). However, direct experimental evidence which has specifically manipulated attention while keeping other aspects of cognition constant has been lacking. For example, Ward & Mann's (2000) distraction condition was not necessarily a controlled manipulation of attention, as it also involved keeping multiple images in short-term memory. As will be outlined in Section 1.5, attention is not thought to be a unitary construct in the context of perceptual load theory. While working memory manipulations affect attention, they are argued to influence a different aspect of attention to perceptual manipulations. In addition, in Ward & Mann's (2000) study, looking at artistic images was also likely to be more engaging and enjoyable than looking at a blank screen and waiting for a beep.

Bellisle and Dalix (2001) used an audio story as a distraction condition, compared to a no task baseline and a focused attention (an audio recording focusing on the sensory characteristics of the food) condition. Participants consumed significantly more when distracted compared to baseline. The focused attention manipulation had no effect. In addition, within the distraction condition, intake was strongly and positively correlated with dietary restraint (TFEQ): for each additional point on the restraint scale, participants consumed an additional 50 calories. However, this relationship was not found in a replication study by the same authors (Bellisle, Dalix, & Slama, 2004). Therefore, while there has been some support that being distracted while eating specifically affects restrained eaters compared to unrestrained eaters, not all studies have found this effect. This suggests that the Restraint Theory approach may not be a sufficient explanation for all inattentive eating.

Boon, Stroebe, Schut, & Ijntema (2002) suggested and tested a modified model of inattentive eating in restrained eaters. The idea was derived from Wegners's ironic process theory, which predicted that attempts to control mental processes caused ironic rebound effects due to limitations in cognitive capacity. Similarly, Boon et al., (2002) predicted that a cognitively demanding distraction task should result in an ironic 'rebound' effect of overeating in restrained but not unrestrained eaters. This effect was predicted to be more pronounced in restrained eaters as their cognitive capacity might be limited by maintaining dieting goals, and therefore they would be unable to maintain focus on both dieting goals and the demanding task. This was tested by presenting participants with ice cream that was perceived to be either 'extra creamy' or '30% lower in calories', while they either listened to a radio conversation (which they had to monitor so they could later answer questions

about its content) or sat in a quiet room. When distracted by the radio, restrained eaters consumed significantly more of the perceived high calorie ice cream (and not the perceived low calorie version) than unrestrained eaters. However, the theoretical predictions were only partially supported, as both restrained and unrestrained eaters both consumed more food when distracted. Several explanations were put forward in an attempt to explain the general inattentive eating effect, including slowed down habituation to food cues and the possibility of unrestrained eaters also relying on cognitive diet boundaries (like those described by the Boundary model—see section 1.4). However, no firm conclusions were drawn.

There has since been a multitude of studies showing a general inattentive eating effect across individuals (Robinson et al., 2013). Recent research has started to investigate the potential mechanisms (Braude & Stevenson, 2014). While dietary restraint has a large impact, a variety of other factors help determine food intake at any given meal. For example, the sensory characteristics of the food (e.g., Mccrickerd et al., 2014), palatability (e.g., Johnson & Wardle, 2014; Sørensen, Møller, Flint, Martens, & Raben, 2003), variety of flavour (e.g., Hetherington, Foster, Newman, Anderson, & Norton, 2006; Martin, 2016), previous expectations about aspects of the food (e.g., Mccrickerd et al., 2014) and interoceptive cues (e.g., Simmons & DeVille, 2017) have all been shown to affect intake when attentional resources are available. Theoretically, being unable to pay attention to any one of these factors could influence intake. Therefore, one way of isolating the mechanisms of inattentive eating is to incorporate an inattentive eating task into a paradigm that manipulates the factor of interest. In this thesis, I choose to focus on whether distraction

would disrupt the processes of flavour perception and satiety in determining meal intake, which will be outlined in the following sections.

1.4.3. Flavour

At the simplest level, people tend to consume more of food that they enjoy and less of food that they don't enjoy. It has been well established that palatable food results in increased consumption (for reviews of this extensive literature see, Drewnowski, 1998; Le Magnen, 1987; Yeomans, 1998). Palatability is defined as the hedonic evaluation of flavour, and the degree to which a food is rated as palatable reliably predicts subsequent consumption. It is also important to define flavour at this point, as flavour refers to the experience of multiple sensory processes involved in eating such as taste, smell and mouthfeel, and is distinct from the precise definition of taste, which refers to the physiological stimulation of taste buds (gustation). In Berridge's (1996) model of 'liking' and 'wanting', palatability reflects liking for food—meaning the sensory pleasure of eating, of which flavour is one component. Palatability has been suggested to motivate consumption through reward mechanisms rather than homeostatic drivers of intake, such as hunger and satiety (the feeling of fullness that suppresses intake) (Although the two processes are not completely separable, for reviews see (Tepper & Yeomans, 2017, Chapter 6; Yeomans, Blundell, & Leshem, 2004). This claim has been supported by studies that have disrupted reward pathways. For example, in human subjects, disrupting the opioid system with opiate receptor antagonists resulted in reduced pleasantness ratings for a variety of food flavours (Bertino, Beauchamp, & Engelman, 1991; Drewnowski, Krahn, Demitrack, Nairn, & Gosnell, 1992; Yeomans, Wright, Macleod, & Critchley, 1990; Yeomans & Wright, 1991; Yeomans & Gray, 1996).

Liking for food has been well established to decline during consumption (Hetherington, 1996). However, while liking for consumed foods decreases, liking for foods that have not been consumed decrease to a lesser extent (Rolls, Rolls, Rowe, & Sweeney, 1981). This phenomenon has been termed sensory specific satiety and has been supported by studies showing that intake for consumed foods is reduced compared to other unconsumed foods that have different sensory qualities (e.g., González, Recio, Sánchez, Gil, & de Brugada, 2018; Griffioen-Roose, Finlayson, Mars, Blundell, & de Graaf, 2010; Raynor & Wing, 2006; Rolls, Van Duijvenvoorde, & Rolls, 1984). For example, intake has been shown to be 60% higher when a four course lunch consisted of four different options than when it consisted of the same food in each course (Rolls et al., 1984). The effect is thought to underlie the ‘buffet effect’ whereby variety of foods promotes intake (Brondel et al., 2009; Epstein, Robinson, Roemmich, Marusewski, & Roba, 2010). While sensory specific satiety is usually discussed in relation to reduced liking for a specific food, the effect may also extend to reduced food wanting (Havermans, Janssen, Giesen, Roefs, & Jansen, 2009).

The mechanisms of sensory specific satiety have not been fully understood. One suggested explanation has been habituation—whereby behavioural response (liking or intake of food) decreases after repeated exposure (consumption) (Raynor & Epstein, 2001). Variety of flavour may disrupt this habituation effect, for example, Brondel et al., (2009) found that hedonic ratings of food (chips and brownies) increased after adding a condiment (ketchup and whipped cream, respectively). In addition, habituation to food is typically accompanied by a decrease in saliva production (Epstein, Rodefer, Wisniewski, & Caggiula, 1992; Epstein, Temple, Roemmich, & Bouton, 2009)—however, when

condiments were added, saliva response returned to baseline levels (Brondel et al., 2009). The effect of sensory specific satiety has also been demonstrated to occur in the absence of awareness in amnesic patients (Higgs, Williamson, Rotshtein, & Humphreys, 2008). This led the authors to conclude that the effect is likely governed by habituation to the sensory properties of the consumed food rather than explicit expectations about normal portion size or memory of intake. However, Mower, Mair & Engen (1977) studied the effect of meal intake on perception of olfactory stimuli and found a reduction in pleasantness but no reduction in perceived intensity, suggesting that any habituation may be limited to pleasantness, which involves cognitive evaluation of the flavour, rather than basic perceptual processes. In addition, the effect can also be achieved by manipulating the perceived variety of foods: participants ate more of chocolate that differed in colour than chocolate of the same colour (Rolls, Rowe & Rolls, 1982). Redden (2008) also manipulated perceived variety by encouraging participants to view available jelly beans at the level of their individual flavour (e.g., cherry) or at the general category level (jelly beans). Participants rated enjoyment of the jelly beans declined less quickly when categorising them at the individual level. Therefore, there are several lines of research suggesting a cognitive component to sensory specific satiety. Moreover, several aspects of sensory specific satiety have not been consistent with a habituation explanation. For example, habituation predicts sensory specific satiety should be stronger when the stimulus intensity is weaker, but research has not supported this (Bolhuis, Lakemond, De Wijk, Luning, & De Graaf, 2011; Essed et al., 2006; Havermans, Geschwind, Filla, Nederkoorn, & Jansen, 2009). A further prediction, according to habituation, was that sensory specific satiety for a food should become stronger after each consumption episode, however, studies assessing sensory specific satiety over multiple meals found no support for the claim (Hetherington,

Pirie, & Nabb, 2002; Hetherington, Bell, & Rolls, 2000; Tey, Brown, Gray, Chisholm, & Delahunty, 2012). It has been suggested that sensory specific satiety comprises a special form of habituation, involving not only a reduction in behavioural response, but a change in affective response to a specific food from positive to negative (Blundell & Bellisle, 2013, Chapter 14). In support of this explanation, one of the most commonly cited reasons by participants for meal termination was ‘I got tired of the food’ (Brondel et al., 2009; Hetherington et al., 2006) and boredom (Blundell & Bellisle, 2013, Chapter 14). This negative emotional state suggests that higher level cognitive evaluations are involved in the process of sensory specific satiety.

Recently, impairment of sensory specific satiety has been implicated in distraction-induced overeating. Braude & Stevenson (2014) manipulated sensory specific satiety by providing participants with either a single snack food or four varieties of snack food while they either watched television or were assigned to a no television condition. Participants rated the foods for their sensory characteristics before and after the experiment. Participants who consumed one snack food compared to four snack foods consumed less food and experienced a greater reduction in food liking during consumption, reflecting a typical sensory specific satiety effect. Those who consumed a single snack food experienced a reduction in liking for that food without television, but no reduction in liking when watching television. Participants who consumed four snack food experienced a similar (but smaller) reduction in food liking, regardless of television condition. Effects on intake followed a similar pattern but were not significant. However, for participants who consumed a single snack food, a smaller change in liking in the television condition was associated with increased intake. Therefore, there was no evidence for sensory specific

satiety when distracted. It should be noted that television in this experiment was also associated with an increase in positive mood, and therefore while attentional mechanisms are possible, alternative explanations such as mood cannot be ruled out.

A potential explanation for distraction-induced increased intake is that distraction reduced awareness of the food's flavour. Several recent studies have suggested that perception of flavour is dependent on having available attentional resources. Van der Wal & van Dillen (2013) tested the effect of a digit span task (participants had to memorise either a one or eight digit number), on flavour perception (the authors used the word taste, but we are using the word flavour as their manipulation better fits onto the way we have defined flavour here) of sour, sweet and salty, solutions and food items. When distracted by the high load digit span task, participants reported all flavour solutions as less intense, consumed fewer crackers spread with salty butter, and added less grenadine syrup to lemonade. The authors concluded that the reduced sensory stimulation caused participants to consume more food/intense flavours to achieve an optimal flavour experience. A similar study instructed participants to memorise letter strings (one or seven letters) while smelling food odours; participants then rated the intensity of the odour after each presentation (Hoffmann-Hensel, Sijben, Rodriguez-Raecke & Freiherr, 2017). Participants rated the odours associated with low calorie food (apples and oranges) as less intense when distracted by the high cognitive load task, and this was associated with lower activity in bilateral orbitofrontal and piriform cortices. However, participants rated high calorie associated odours (chocolate and caramel) equally under both low and high cognitive load. Despite the lack of behavioural differences, activation of piriform cortices in response to high calorie associated odours was reduced under high cognitive load, but there was no

effect of task load on bilateral orbitofrontal cortices activation. It is not entirely clear why intensity ratings of high calorie associated odours were less affected by cognitive load. However, high calorie visual food stimuli have been found to preferentially capture attention compared to low calorie food stimuli (Castellanos et al., 2009). Therefore, it's possible that high calorie odours would also have an attentional advantage, even under high cognitive load. These initial studies indicate that having attentional resources available may be necessary for the processing of flavour, potentially on a neural level (with the exception of high calorie stimuli).

To summarise, palatability has a strong influence on intake, although liking for food tends to decline over the course of a meal (sensory specific satiety). However, disrupting sensory specific satiety with flavour variety reduces the typical decrease in liking and termination of intake. One potential explanation for the effect of sensory specific satiety has been habituation, but this has not been fully supported by research. Cognitive mechanisms have also been implicated in the effect, such as reduced affective response to food and boredom. More recently, attention has been suggested as a potential mechanism (Braude & Stevenson, 2014), as being distracted by television can disrupt the process of sensory specific satiety—although, as previously pointed out, other factors such as mood cannot be ruled out. One potential explanation for the effect of distraction on sensory specific satiety could be that the distraction task reduced attention paid to the flavour of the food. There has now been one study demonstrating that distraction may directly reduce flavour awareness (van der Wal & van Dillen, 2013), and a further study showing similar effects with food odours (Hoffmann-Hensel, Sijben, Rodriguez-Raecke, & Freiherr, 2017). This initial evidence is promising, however, further tests within an eating context are needed.

1.4.5. Satiety

In contrast to palatability, satiation (the process that causes cessation of intake) and satiety (the feeling of fullness after a meal that suppresses intake) have been understood to primarily control appetite and intake through homeostatic mechanisms. The extent to which people rely on these physiological cues has been typically tested using a preload design, in which participants consume a ‘preload’ (usually a food or beverage) which has been manipulated on at least one crucial variable between conditions (e.g., calories or nutrient composition) (for review of the preload method see, Blundell & Bellisle, 2013, Chapter 2). Usually, when offered food at a later time-point, participants will compensate their intake according to the type of preload they ingested. For example, a participant should consume less food after consuming a high energy preload compared to a low energy preload. Often, visual analogue scales will also be administered before and after the preload to measure subjective changes in appetite. There is substantial evidence for typical preload compensation effects on both intake and subjective measures (for review see, Almiron-Roig et al., 2013).

Several approaches to appetite control, particularly gut-brain models, have been exclusively physiological and allowed no role for cognitive influences (Hellström, 2013; Hussain & Bloom, 2013; Sclafani, 2013). Such theories focus on the release of hormones indicating the absorption of nutrients in the small intestine. For example, ghrelin is a hormone associated with hunger, and its suppression contributes to satiety (Klok, Jakobsdottir, & Drent, 2007). There are also longer term ‘tonic’ satiety signals, such as baseline levels of leptin and insulin which vary according to body fat. For reviews of the different hormones associated with appetite control see Benelam (2009), Gibson, Carnell,

Ochner and Geliebter (2010) and Hellström (2013). Once generated, satiety signals are integrated in the brain. Early animal experiments highlighted the hypothalamus as a central brain region to appetite control (Morgane & Jacobs 1969). The hypothalamus is thought to control appetite via homeostatic mechanisms, and two main pathways have been identified: one that inhibits (anorexigenic) and another which stimulates (orexigenic) food intake (for reviews see, Berthoud & Morrison, 2008; Sohn, 2015). Gut-brain models were originally entirely physiological, but more recently the role of non-biological factors have been emphasised (Dalton, Finlayson, Esdaile, & King, 2013; Shin, Zheng, & Berthoud, 2009).

Models like the ‘Satiety Cascade’ have approached appetite control in a more holistic manner, by incorporating a variety of environmental and psychological factors. The model was originally proposed by Blundell, Rogers and Hill (1987), and has been subsequently modified by several research groups (Blundell et al., 2010; Blundell, 1991; Mela, 2006). The most recent version of the Satiety cascade (see Figure 1) outlined the processes involved in generating satiation and satiety, which tend to be split into early cognitive and sensory influences, and later post-ingestive influences. The former has tended to refer to psychological processes, whereas the latter referred to the biological processes described above. The adaptation of the model to include psychological influences was due to increasing evidence that individuals did not show the precise caloric compensation that tightly controlled biological accounts of appetite control would predict (Kral, Roe, & Rolls, 2004; Levitsky, 2005). A variety of cognitive and sensory factors, including expectations (e.g., whether a beverage is consumed in the context of a drink or a snack) (Mccrickerd et al., 2014; Yeomans, 2015), palatability (liking) (Johnson & Wardle, 2014; Sørensen et al., 2003), variety of flavour (Hetherington, Foster, Newman, Anderson, & Norton, 2006;

Martin, 2016), portion size (Herman, Polivy, Pliner, & Vartanian, 2015; Steenhuis & Poelman, 2017) and food texture (Mccrickerd et al., 2014), have all been shown to influence satiation and satiety.

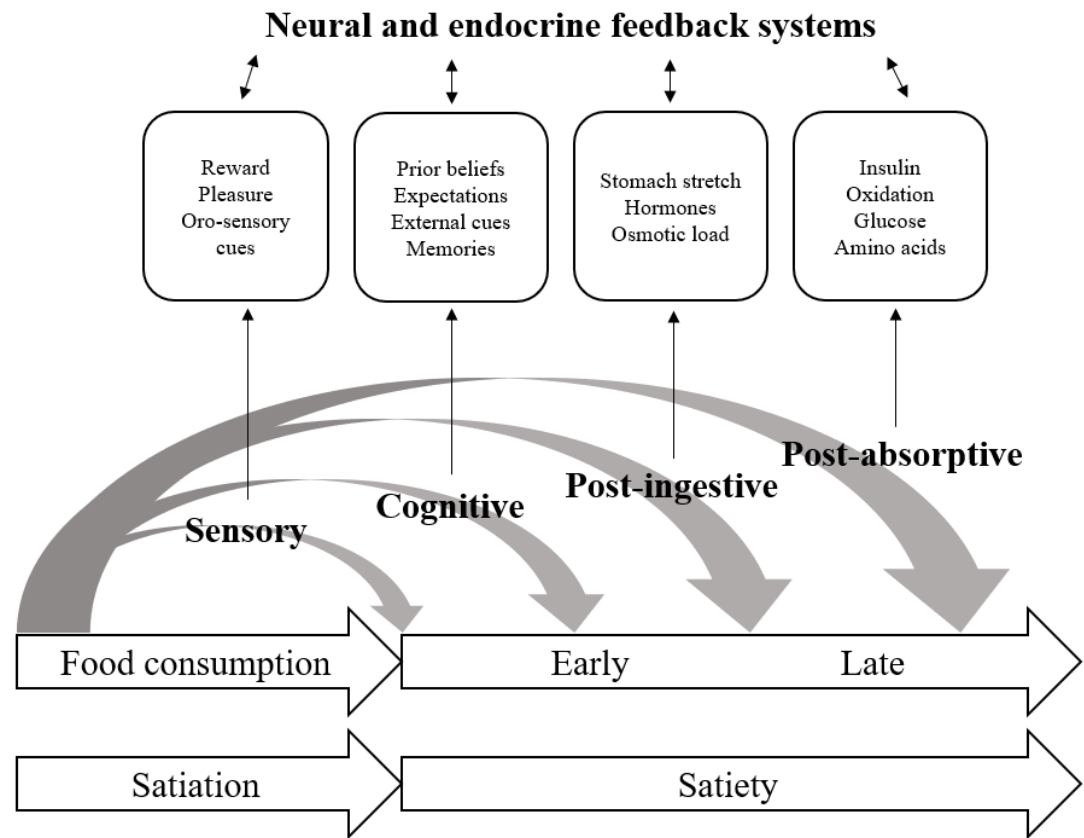


Figure 1. A modified example of the 'Satiety Cascade', illustrating the integration of early (sensory and cognitive) and late (post-ingestive and post-absorptive) influences on satiation and satiety (adapted from Blundell et al., 2010).

More recently, there has been research interest in understanding the specific cognitive mechanisms involved in appetite control, with a particular focus on memory. The vicious cycle model suggests that information about intake (including satiety) is stored as memory and this guides subsequent food-related decision making (Davidson, Sample & Swithers, 2014; Davidson, Jones, Roy & Stevenson, 2019). Figure 2 shows how individuals learn excitatory associations between food cues and the positive post-ingestive consequences of eating, while satiety strengthens inhibitory associations by providing information about negative post-ingestive consequences (feeling full) and limiting subsequent intake via a ‘hippocampal-dependent gating mechanism’. Exposure to a western diet (which is typically high in sugar and fat) has a damaging effect on the hippocampus (the neural region key to the storage and integration of food-related information in the brain), which results in cognitive deficits that further promote intake of a western diet; this pattern continues in a ‘vicious cycle’ that impairs the hippocampal function and contributes to overeating and weight gain. While it has been highlighted that the majority of evidence for the vicious cycle model comes from animal studies (Yeomans, 2017), recent human research has been consistent with its predictions (Attuquayefio et al., 2016; Stevenson & Francis, 2017).

A recent review by Higgs & Spetter (2018) further outlines how memory processes guide a range of eating behaviours. For example, working memory guides attention towards food-related cues, then once eating has begun working memory allows attention to be paid to the eating experience (which presumably includes satiation, although there is little direct evidence testing this idea) and maintaining focus on long term goals (e.g., dieting). Episodic memory plays a role in eating behaviour by providing information about recent

eating experiences and amount consumed – which should influence subsequent intake accordingly. Episodic memory may also be specifically related to satiety, as poor performance on an episodic memory task has been linked to reduced recall accuracy of previous intake and reduced sensitivity to signals of hunger and satiety (Attuquayefio et al., 2016).

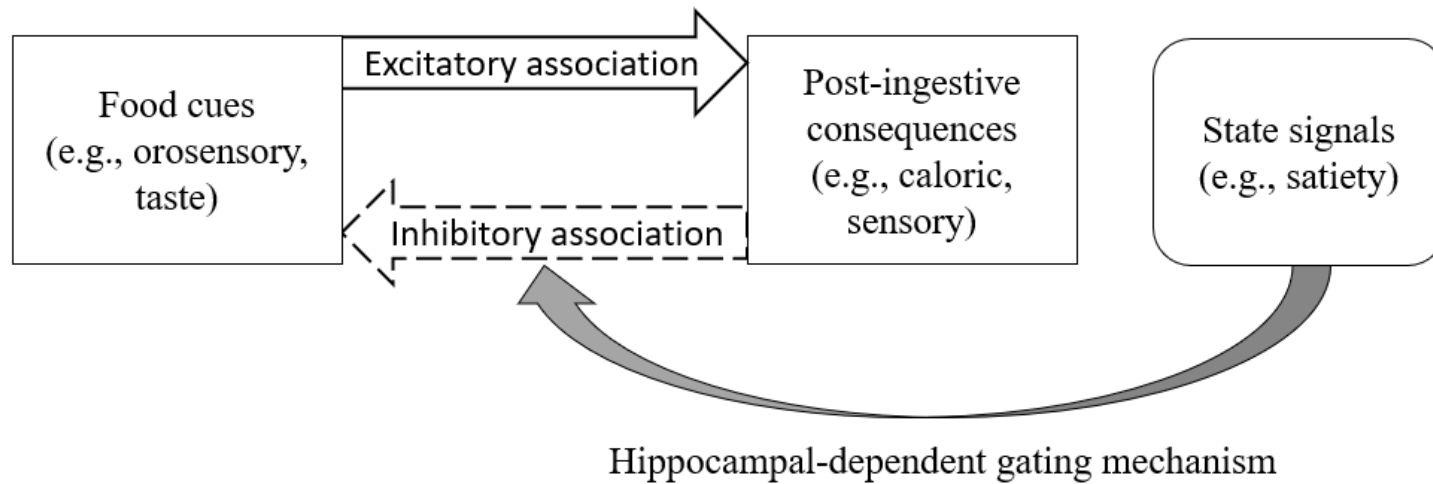


Figure 2. A modified example of cognitive mechanism underlying appetite control in the vicious cycle model (adapted from Davidson et al., 2019).

A recent experiment further highlighted the potential role of attention in satiety. Bellissimo et al., (2007) ran a within subjects preload manipulation on child participants, who consumed a liquid preload (Splenda sucralose or 1g/kg body weight glucose—average body weight was 49.9kg) and were subsequently given ad libitum access to a pizza meal, which they ate either with or without watching television. Without television, participants reduced their intake by 104 calories after receiving the glucose preload compared to the sucralose. When watching television, participants reduced their intake to a lesser extent of 69 calories. Television increased intake overall but crucially the compensation effect was only found in the no television condition, suggesting that being distracted interfered with response to satiation and/or satiety signals. No effect was found on subjective appetite ratings. The authors concluded that television may result in increased intake by delaying normal satiation and satiety. However, underlying mechanisms were not discussed. Given that television has often been used as a distraction task in the eating behaviour literature, lack of attention could be a potential mechanism (although attention was not explicitly manipulated and other, previously mentioned alternative explanations such as mood cannot be ruled out).

A wider line of research has investigated the effect of distraction on subsequent intake. Higgs (2015a) gave participants a set lunch, which they consumed while either playing a video game or watching television (in comparison to a no distraction control). Across multiple studies, being distracted at the time of eating increased subsequent intake at a disguised snack test. Subsequent studies have replicated the effect of distraction on subsequent intake (Higgs & Woodward, 2009; Mittal, Stevenson, Oaten, & Miller, 2011; Oldham-Cooper et al., 2010) and a meta-analysis concluded that distraction influences

subsequent intake more strongly than immediate intake (Robinson et al., 2013).

Manipulations of attention have been argued to influence subsequent intake via changes in meal memory (Higgs & Spetter, 2018; Robinson, Kersbergen, & Higgs, 2014). In support of this claim, when food is consumed whilst distracted, subsequent memory ratings for vividness of the food and accuracy of which food items had been consumed were reduced (Higgs, 2015a). Clearly attention and memory are both implicated in the effect of distraction on subsequent intake, however, it is not known what the relative contributions are. On the one hand, intake-related information may have been fully processed at the time of consumption, and only subsequent memory was affected. On the other hand, the effect of distraction on subsequent intake could represent a fundamental attentional effect, where intake-related information did not receive processing from the earliest point of perception. The attentional manipulation could have also affected multiple aspects of eating behaviour—for example reduced memory for sensory aspects of the food (e.g., palatability), cognitive factors (e.g., how much was consumed relative to dieting goals) and internal signals (e.g., satiety), could have all potentially affected subsequent intake. The factor of interest in this thesis was satiety. The effect of distraction on subsequent intake is potentially consistent with the idea that attention has an impact on satiety. A few of these studies also measured subjective appetite, however, findings have been mixed. For example, Oldham-Cooper et al., (2010) found that those who consumed food whilst distracted were also less full after the meal. However, several studies have found no effect of distraction condition on appetite ratings (Higgs, 2015; Mittal et al., 2011). At the time of this thesis, none of the studies in this literature (effect of distraction on subsequent intake) had isolated the effects of an attentional manipulation on satiety.

1.4.5. Summary: the role of attention in eating behaviour during consumption

To summarise, the reviewed research has shown that disrupting attention during food consumption impacts both immediate and subsequent intake. This effect is most frequently studied by measuring intake when food is presented with distraction (usually television) compared to a no distraction condition. However, the mechanisms behind this effect are not well understood. Theoretical approaches have most often focused on restrained eaters, as their cognitive capacity is thought to be reduced by their dieting goals. However, inattentive eating has been observed across individuals, suggesting that Restraint Theory is unable to explain all inattentive eating. More recently, research has attempted to identify the underlying mechanisms of inattentive eating and cognitive processes, such as attention and memory, have been implicated. Research has suggested the relevance of attention in several modulators of intake including flavour and satiety. Perceptual load theory of attention is based on a limited perceptual capacity model, whereby sensory stimuli do not receive attentional processing in demanding situations (such as when a participant is engaged in a distracting task). This thesis will test a stronger attentional explanation of the research described in Section 1.4, expanding upon previous research by testing which aspects of eating behaviour are dependent on having attentional resources available to process them. These findings could be used to identify situations where attention can help/hinder eating-related goals and test the limits of perceptual processing in complex behaviours.

1.5. Perceptual load theory of attention

Selective attention is the mechanism by which relevant information is prioritised for cognitive processing and irrelevant information is suppressed. Perceptual load theory is

now one of the most influential limited capacity models of how this process occurs. Prior to perceptual load theory, attention research was split between early and late selection models. On the one hand, early selection theorists such as Treisman (1969) argued that an attentional filter enabled only relevant information to be selected for further processing at an early stage. On the other hand, supporters of late selection such as Duncan (1980) and Deutsch and Deutsch (1963) argued that both irrelevant and relevant information were fully processed, and that attention could only influence postperceptual processes such as memory. A solution proved difficult due to evidence supporting both approaches, even within the same paradigm, such as the Stroop task. There are many variations of the Stroop task, but typically the participant has to identify a target (e.g., the identity of a letter) while ignoring competing irrelevant information (e.g., letters in the incorrect location). The Stroop effect is usually demonstrated by the participant being slower to identify the target when the irrelevant information is incongruent (e.g., if the target letter is X and the irrelevant letter is N) compared to when it is congruent (e.g., both the target and irrelevant letter are X). The Stroop task has been argued to show evidence for late selection, as slower responses to incongruent pairings suggests that the distractor was processed (Eriksen & Eriksen, 1974). However, very similar versions of the same task have been argued to support early selection. For example, cueing attention or cluttering the display reduced the typical incongruent Stroop effect, suggesting that the distractor did not interfere with participants ability to focus on the target letter, and therefore the distractor did not receive attentional processing (Kahneman & Chajczyk, 1983; Yantis & Johnston, 1990). Perceptual load theory combined these conflicting approaches to attention research by identifying two independent mechanisms by which stimuli could be selected at both early and late stages: perceptual and cognitive.

The perceptual mechanism of attentional selection operates at an early stage where irrelevant information is only processed when there is spare attentional capacity. Increasing the level of perceptual load (e.g., by increasing the setsize in a display, Forster & Lavie, 2008; Lavie, 1995) exhausts this attentional capacity and results in distracting information being filtered out. Crucially, this is a passive process that is carried out automatically by the perceptual system. In contrast, the cognitive mechanism only operates at the later stage of selection; it relies on higher order cognitive processes to maintain relevant prioritisation and is therefore an active process. Increasing the level of cognitive load (e.g., by taxing working memory via a digit span task, Lavie, Hirst, de Fockert, & Viding, 2004) undermines cognitive control, resulting in increased distraction as irrelevant stimuli cannot be ignored.

1.5.1. Evidence for perceptual load theory

Early evidence for perceptual load theory came from Lavie's (1995) experiments demonstrating that, in contrast to cognitive load, perceptual load reduced distractor interference from irrelevant stimuli. Participants had to search for a target letter in a display while ignoring an incongruent or congruent distractor. Perceptual load was manipulated in a variety of ways to ensure the effect was not dependent upon a single paradigm. Firstly, via increasing the setsize in a simple visual search task; the target letter was presented alone or with five nontarget letters (Low perceptual load shown in Figure 2a and high perceptual load shown in Figure 2b). In subsequent experiments participants completed a Go/no-go task, where they responded to the target letter only when the correct additional shape also appeared in the display. Perceptual load was manipulated by altering the perceptual demand involved in the Go/no-go decision. Under low perceptual load, the go/no-go decision

involved a simple feature: participants responded to the letter target (X or N) when the simultaneously displayed circle was blue and withheld their response when it was red (Figure 3a). Under high perceptual load, the go/no-go decision involved a conjunction of features: participants responded when a red circle or blue square was present but withheld their response when a red square or blue circle was present (Figure 3b). Across four experiments, the congruency effect (demonstrated by slower reaction times) between target and distractor was found under low but not high perceptual load.

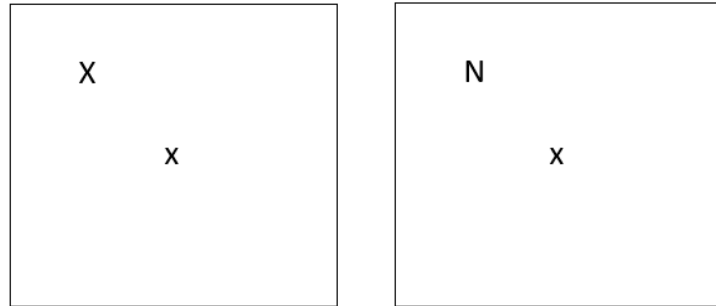


Figure 2a: Congruent (left) and incongruent (right) low perceptual load stimuli displays.

Target letter (X/N) is presented at fixation and the slightly larger distractor letter (X/N) is presented in a periphery location.

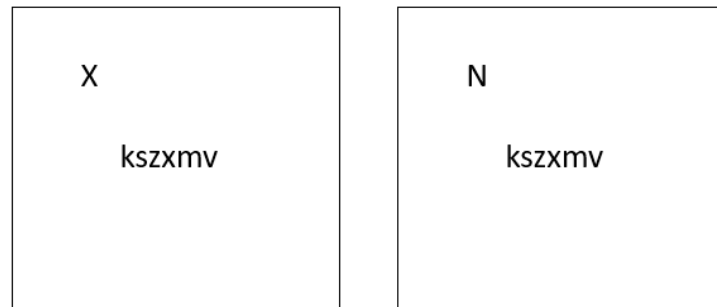


Figure 2b: Congruent (left) and incongruent (right) high perceptual load stimuli displays.

Target letter (X/N) is presented in central line and the slightly larger distractor letter (X/N) is presented in a periphery location.

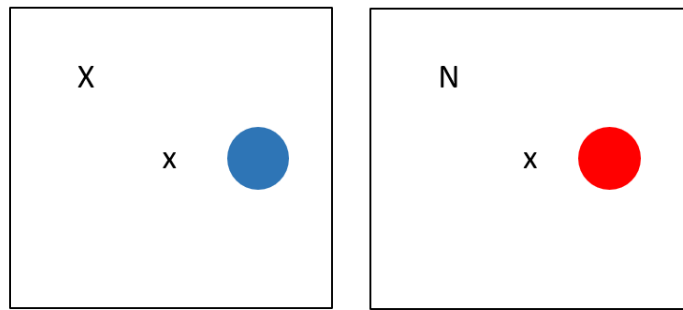
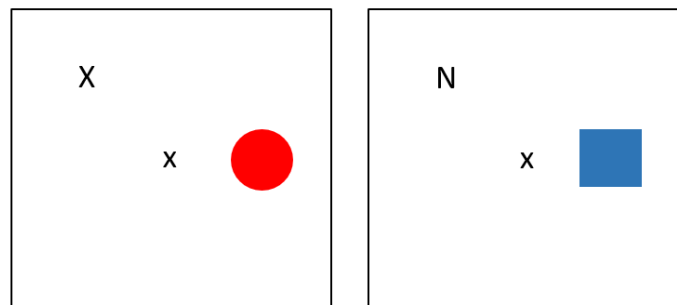


Figure 3a: Congruent Go (left) and incongruent No-go (right) low perceptual load (colour features only) stimuli displays.

Go trial:
presence of
red circle or
blue square



No-go trial:
presence of
blue circle or
red square

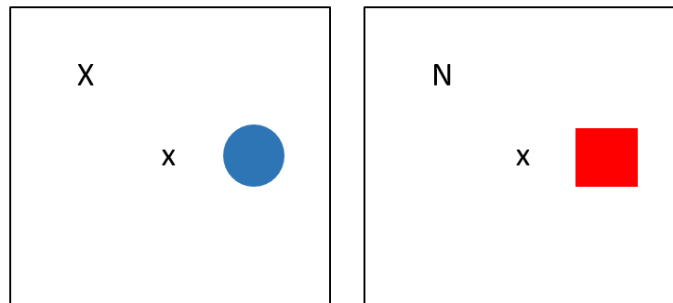


Figure 3b: Congruent (left) and incongruent (right) high perceptual load (conjunctions of colours and shapes) stimuli displays.

There is now a large body of evidence showing reduced distractor interference under high perceptual load (Elliott & Giesbrecht, 2010; Lavie & De Fockert, 2003; Torralbo & Beck, 2008; Wei, Kang, & Zhou, 2013). Perceptual load has been shown to reduce processing across a variety of paradigms (for reviews see, Lavie, 2005, 2010; Murphy, Groeger, & Greene, 2016). For example, high perceptual load reduces negative priming (slower responses to previously seen stimuli: Lavie & Fox, 2000) and action affordances (the tendency of graspable objects to afford associated actions: Murphy, van Velzen, & de Fockert, 2012). Perceptual load has also been shown to affect subsequent processes, such as memory—recognition of stimuli presented under high perceptual load has been found to be lower than stimuli presented under low perceptual load (Jenkins, Lavie, & Driver, 2005). Furthermore, while the majority of research focusing on the processing of external stimuli, perceptual load has been found to modulate internal processing in the same manner. In everyday life, people may experience spontaneous thoughts completely unrelated to their current task. For example, while reading an article they might wonder what to have for dinner. Forster and Lavie (2009) found that participants reported significantly fewer task unrelated thoughts (in response to probe questions) when engaged in a high compared to low perceptual load task. Therefore, perceptual load interferes with a range of processes, and is not limited to simple external visual distraction.

Several studies have shown that perceptual load reduced awareness of a critical stimulus, by integrating a perceptual load manipulation into inattention blindness paradigms (Calvillo & Jackson, 2014; Cartwright-Finch & Lavie, 2007; Macdonald & Lavie, 2008). Cartwright-Finch & Lavie (2007) used both a visual search task, almost identical to that used by Lavie (1995), and a perceptual judgement task to manipulate load.

In the perceptual judgement task, under low perceptual load participants made a simple colour discrimination response (which of a set of blue and green lines was blue — when the colours were clearly different) or under high perceptual load, a subtle line-length discrimination task (which of two similar length lines was longer). On the last trial, a critical stimulus (a black square) appeared in the display. In both tasks, awareness of the critical stimulus was significantly reduced under high perceptual load. Inattentional blindness experiments have been suggested to indicate a role of perceptual load in conscious awareness of external stimuli (Konstantinou, Beal, King, & Lavie, 2014), as they do not rely on reaction time measures which could be argued to show an effect of perceptual load on response behaviour rather than perception.

Studies investigating neural processing under perceptual load have elaborated on the underlying mechanisms. High perceptual load has been repeatedly found to reduce distractor-related neural activity, further suggesting that the perceptual load effect reflects reduced distractor perception rather than an altered behavioural response (Schwartz et al., 2005; Sy & Giesbrecht, 2010; Yi, Woodman, Widders, Marois, & Chun, 2004). Evidence has suggested that perceptual load operates at an early stage of processing. Schwartz et al., (2005) measured neural activity related to task irrelevant checkerboard patterns while participants completed a low or high perceptual load task (monitoring rapidly presented letter streams). They found that neural activity in the visual cortex was reduced even in V1 (and the perceptual load effect increased in magnitude from V1 to V4). O'Connor, Fukui, Pinsk, & Kastner (2002) also found that perceptual load reduced V1 activity. In addition, perceptual load reduced activity in the Lateral Geniculate Nucleus, which is viewed as the first point of entry of sensory information into the visual cortex. These studies support the

idea of perceptual load filtering out irrelevant information at both at the earliest stage and throughout subsequent visual processing. While most studies have focused on the visual mechanisms, perceptual load also affects associated processes. For example, the amygdala response to emotional face expressions is eliminated by high perceptual load in non-anxious individuals (Pessoa, McKenna, Gutierrez, & Ungerleider, 2002) and those high in state and trait anxiety (Bishop, Jenkins, & Lawrence, 2007).

To summarise, there has been a wealth of research demonstrating that perceptual load is a robust manipulation of attention across multiple paradigms. Research suggests that perceptual load filters out irrelevant information at an early stage, influencing whether that information reaches conscious awareness and subsequent processes such as memory. Given the role of attention in eating behaviour (highlighted in Sections 1.3-1.4), the application of perceptual load theory in this area could further illuminate the underlying mechanisms of food-related cognition and consumption. At present, perceptual load has not been tested in relation to food. However, several studies testing inattentive eating have found results that are consistent with the second aspect of perceptual load theory: cognitive load.

1.5.2. The role of cognitive load

An advantage of perceptual load theory is that it can distinguish between different types of task load. While perceptual load reduces distraction by irrelevant stimuli, load on cognitive control functions, such as working memory, increases distraction by undermining stimulus prioritisation. Lavie, Hirst, de Fockert, & Viding (2004) tested cognitive load by instructing participants to search for a target letter (X/N) while ignoring the congruent/incongruent distractor letter. Cognitive load was manipulated by instructing participants to hold one (low cognitive load) or six (high cognitive load) digits in working

memory. The congruency effect of target and distractor was significantly increased under high cognitive load across multiple experiments. Numerous studies have found evidence for increased distraction under high cognitive load (Burnham, 2010; Kelley & Lavie, 2011; Lavie & De Fockert, 2005; Lavie et al., 2004; Rissman, Gazzaley, & D'Esposito, 2009).

The role of cognitive load has been tested within the inattentive eating literature. While studies using the term 'cognitive load' may not be explicitly referring to that described by perceptual load theory, the method used to manipulate load has often overlapped. For example, Mann and Ward (2004) had participants rehearse a one or nine digit number (low vs high cognitive load) while they consumed a milkshake. Participants either took part in a 'milkshake salient' (participants were told to focus on the taste) or 'diet salient' condition (participants filled out the Dutch eating behaviour questionnaire, they were told the milkshake was high in fat and dieting books and scales were left in the participants view). Under low cognitive load, there was no difference in consumption depending on salience condition. Under high cognitive load, participants consumed significantly more of the milkshake in the 'milkshake salient' compared to the 'diet salient' condition. The authors explained this result via the attentional myopia model of behavioural control, which suggests that salient internal and external cues will disproportionately influence behaviour when attentional capacity is limited. However, the findings are also consistent with cognitive load, as performing the high cognitive load task would have likely increased processing of non-task stimuli such as the milkshake and the dieting cues. In a similar cognitive load manipulation, Zimmerman & Shimoga (2014) exposed children to food advertisements while they rehearsed either a two or seven digit number and found that children ate the greatest amount of food after seeing food advertisements under high cognitive load. These findings are in line with perceptual load theory, as high cognitive

load in the digit span task should have increased processing of the non-task food advertisements. Therefore, the ability of the advertisements to increase consumption may have been increased under high cognitive load.

Moreover, the role of working memory (which cognitive load is known to tax) is heavily implicated in both food processing and eating behaviour (for review see Higgs & Spetter, 2018). Working memory enables an individual to maintain attention to long term health/diet related goals (Hofmann, Gschwendner, Friese, Wiers, & Schmitt, 2008). Conversely, deficits in working memory function have been linked to obesity (Coppin, Nolan-Poupart, Jones-Gotman, & Small, 2014). One of the reasons that maintaining a dieting goal is thought to contribute to overeating is due to the extra demand it places on cognitive processes—for example, dieters experience more preoccupying thoughts about food (Shaw & Tiggemann, 2004; Vreugdenburg, Bryan, & Kemps, 2003). Successful dieting may be at least partly mediated by working memory capacity (Stroebe et al., 2017; Whitelock, Nouwen, van den Akker, & Higgs, 2018). What is notable in this literature is that cognitive load has been effectively applied to the broader framework of eating, but perceptual load has not, and for that reason this thesis sets out to explore perceptual load effects on different aspects of eating for the first time.

1.5.3. The application of perceptual load theory to eating behaviour

The following sections will discuss the potential application of the perceptual load theory of attention to the eating literature. Perceptual load theory makes clear and testable predictions about attention in the real world and research has begun to apply these in scenarios where attention has important consequences, such as driving (Marciano & Yeshurun, 2015; Murphy & Greene, 2015, 2017) and eyewitness testimony (Murphy &

Greene, 2016). However, prior to this thesis, there were no published studies applying perceptual load theory to any aspect of eating behaviour.

As previously outlined (sections 1.3-1.4), attention is known to have a different impact on food and eating behaviour depending on which stage of ingestion is being considered. Prior to consumption, attention to food is generally considered to have a negative influence on potential over consumption. This is due to attention increasing the salience of both external and internal food-related cues, which in turn has been shown to increase the risk of subsequent craving and consumption (outlined in sections 1.3.1 and 1.3.4). In this context, diverting attention away from food (e.g., by occupying attention in a task) should have the effect of disrupting this cycle and would therefore be beneficial for those trying to resist their food cravings. As perceptual load reliably exhausts attentional capacity, it could prove to be a useful method to reduce biased attention and thoughts relating to food. In addition, as perceptual load is known to be a passive and automatic process, it may be more practically useful than the typical attentional retraining processes described earlier as attempts to modulate attention to food (section 1.3.3) which are time consuming and effortful.

However, some classes of stimuli have been found to be immune to the effect of perceptual load, suggesting that they hold some ‘special’ status in processing. For example, musicians but not non-musicians were still distracted by musical instruments under high perceptual load (Ro, Friggel, & Lavie, 2009). Other potential categories that may be less affected by perceptual load include faces (Lavie, Ro, & Russell, 2003), positive stimuli (Gupta, Hur, & Lavie, 2016) and familiar natural stimuli (He & Chen, 2010). Therefore, the application of perceptual load theory will also establish to what extent food cues hold any

‘special’ influence over perceptual processing. This is a central question in the eating behaviour literature, with some studies suggesting that attention is biased towards food stimuli and others suggesting they hold no advantage over similarly salient stimuli (Doolan et al., 2015; Field & Cox, 2008; Hendrikse et al., 2015; Nijs & Franken, 2012; Werthmann et al., 2015).

In contrast, inattentive eating studies suggest that paying attention to food during ingestion is important for avoiding overeating (outlined in section 1.4.2). In particular, maintaining dieting goals has been thought to be cognitively demanding (Boon et al., 2002; Stroebe et al., 2017) and therefore overeating occurs due to the difficulty of maintain both dieting goals and focusing on a distracting task, implying that cognitive capacity is limited. However, this capacity is thought to be a general cognitive resource (involving multiple aspects of cognition such as attention, memory and executive control, rather than the specific perceptual capacity proposed by perceptual load theory), and the specific mechanisms have not been defined or tested. In addition, we may overeat due to a variety of reasons, including lack of flavour awareness and inattention to internal satiety signals. Logically, a limited capacity model should predict that exhausting capacity would take attentional resources away from processing both flavour awareness and internal satiety signals. However, crucially, neither of these explanations has been explicitly tested. Applying perceptual load theory to both of these areas of eating behaviour develops previous inattentive eating research and establishes the role of a potentially overlooked determinant of intake: perceptual load.

Another advantage of a perceptual load theory framework of eating behaviour is the ability to distinguish between task loads. Previous studies across different areas of eating

research have used a variety of tasks to manipulate attention. For example, the following tasks have been used in inattentive eating studies: video games (e.g, Higgs, 2015a), television (e.g, Braude & Stevenson, 2014), radio (e.g., Boon et al., 2002), audio stories (e.g., Long et al., 2011), digit span (e.g., Mann & Ward, 2004) and memorising images (e.g., Ward & Mann, 2000). It is unclear to what extent these tasks are manipulating perceptual or cognitive load. For example, the video game used by Higgs (2015a), where the player has to navigate a helicopter through increasingly small gaps, is likely to be perceptually demanding, similar to the perceptual load task where participants have to make a judgment on the length of two very similar lines. However, the task may also be manipulating cognitive demand in comparison to the no task control. Establishing how perceptual load affects attention to food and eating behaviour will enable future research to manipulate the intended type of load and be specific about the attentional mechanism responsible. Finally, applying the same attentional manipulation across multiple aspects of eating behaviour allows for comparison and linking between traditionally separate sub-literatures.

1.5.4. Individual differences in eating behaviour under perceptual load

A secondary question in this thesis was to test whether individual differences in eating behaviour interacted with the effect of perceptual load. Within the perceptual load theory literature, several studies have found that perceptual load reduces distractor processing regardless of individual differences (Bishop, Jenkins, & Lawrence, 2007; Forster & Lavie, 2007; Forster & Lavie, 2009; Forster, Robertson, Jennings, Asherson, & Lavie, 2014). For example, Forster & Lavie (2007) found that participants who reported greater distractibility in their everyday life (measured with the cognitive failures

questionnaire) were also more distracted by irrelevant visual distractors under low perceptual load. However, this individual variation was not found under high perceptual load, suggesting that distraction was reduced across participants. A number of individual differences have also been observed in the cognitive processing of food stimuli and intake. Dietary restraint, for example, has been linked to biased attention to food cues (e.g., Hollitt, Kemps, Tiggemann, Smeets, & Mills, 2010) and susceptibility to inattentive eating paradigms (e.g., Ward & Mann, 2000), as reviewed in detail earlier (Section 1.3-1.4). Therefore, it may be that individuals scoring highly on traits such as dietary restraint would show greater attentional bias to food cues under low perceptual load but would still experience a reduction under high perceptual load.

However, some individuals (such as those with autism spectrum disorders, Remington, Swettenham, Campbell, & Coleman, 2009) have a larger perceptual capacity, and therefore a higher level of perceptual load is needed to exhaust it. However, individual differences within the eating behaviour literature are often measured as behavioural traits such as Dietary restraint, and it is unknown if and how these would relate to perceptual capacity. Capacity limits may also be dependent on the situation. For example, when state anxiety was induced by the threat of electric shocks, threat stimuli were preferentially attended to even under high perceptual load (Cornwell et al., 2011). Therefore, state differences in eating behaviour, such as hunger, could potentially alter capacity limits in relation to food stimuli. For example, hungry individuals may still process food stimuli, even under high perceptual load.

Given the limited number of situations where individual differences in attentional processing persist under high perceptual load, identifying them is particularly interesting as

it establishes the limits of perceptual load. In addition, it is completely unknown how eating-related traits would interact with perceptual load in a complex eating scenario, given the effect of perceptual load in this context is currently untested. Therefore, it was important in this thesis to measure individual differences in eating behaviour.

1.5.5. Cross-modal effects of perceptual load in eating behaviour

Both a challenge and opportunity in the application of perceptual load theory is that research on cross-modal effects of perceptual load has been contentious (Murphy, Spence, & Dalton, 2017). This represents a potential issue, as it is possible that perceptual load will not modulate processing of consumption processes such as flavour and satiety. However, despite disagreement to whether perceptual load can act cross-modally, recent research has extended the effect of perceptual load beyond the visual domain. For example, visual perceptual load (manipulated via the visual search task) has been found to reduce awareness of tactile stimuli (participants were less aware of vibrations delivered to the hand: Murphy & Dalton, 2016), olfactory stimuli (participants did not notice the smell of coffee: Forster & Spence, 2018) and auditory stimuli (participants did not notice a tone played on the final critical trial of the task: Macdonald & Lavie, 2011). Similar to previous research, perceptual load has been found to reduce neural activity associated with auditory distractors as an early stage of processing, suggesting cross-modal effects of perceptual load rely on similar early selection mechanisms (Molloy, Griffiths, Chait, & Lavie, 2015). Failure of perceptual load to modulate distractor processing across sensory modalities has been most frequently observed with auditory manipulations of perceptual load (Jacoby, Hall, & Mattingley, 2012; Murphy, Fraenkel, & Dalton, 2013; Rees, Frith, & Lavie, 2001), with only a few exceptions (Fairnie, Moore, & Remington, 2016; Francis, 2010). Murphy,

Spence and Dalton (2017) reviewed the auditory perceptual load literature and suggested that auditory attention may lack a strong mechanism of attentional selection, and therefore is integrated through the perceptual system into ‘streams’ that only then receive focused attention. As a result, full capacity is less likely to be absorbed by relevant auditory tasks, even when the task is perceptually demanding. Therefore, while the cross-modal perceptual literature is somewhat inconsistent, this issue is more prevalent with auditory compared to visual perceptual load tasks.

While there is substantial evidence that visual perceptual load can reduce processing across a range of sensory modalities, it will be vital to establish the cross-modal effects of perceptual load in the context of eating behaviour. The ability of perceptual load to modulate cross-modally determines whether perceptual load theory is a viable framework for understanding cognitive influences on eating behaviour. However, the proposed research also represents an advance in attention research, as applying perceptual load theory to a previously untested area will help further define the parameters of the theory.

1.6. A perceptual load theory framework of eating behaviour: research aims and outline

As reviewed in this introduction, there is substantial evidence to suggest that attention plays an important role throughout the eating process. The research outline in this overview has highlighted several key areas of research investigating the role of attention in eating behaviour including attention to external food cues, internal intrusive food-related thoughts, flavour awareness and internal satiety signals. The primary aim of this thesis is to establish which of these aspects of eating behaviour are dependent on having basic perceptual capacity available. In terms of processes that occur before consumption, high

perceptual load should have a beneficial effect by disrupting negative attentional orienting towards food-related cues and thoughts, whereas once consumption has started, high perceptual load should have a negative effect by undermining the individual's ability to process aspects of eating intended to act as natural intake stopping signals. The secondary aim of this thesis was to control for individual differences in eating-related characteristics across studies and, where possible, investigate how these individual differences interacted with perceptual load.

In order to make comparisons across experiments about the effect of perceptual load, the perceptual load manipulation was kept as similar as possible. The same essential visual search task was used in every experiment (with slight alterations in Paper Three and Four to allow for food consumption). In addition, several trait individual difference measures which had been strongly linked to multiple aspects of eating behaviour were included across experiments: dietary restraint, disinhibition, external eating and impulsivity. Each measure was selected based on a review of the relevant literature for each paper (attentional bias, food-related thoughts, flavour responsiveness and satiety)—the reasons for including each measure will be outlined in more detail in individual paper method sections.

1.6.1. Paper one: Testing a perceptual load theory framework for food-related cognition

Food cues are thought to be prioritised in cognitive processing due to their association with reward (Anderson, 2016; Berridge, 2009). The majority of research, and dominant theoretical approaches, have focused on attentional bias as a hallmark of this prioritised processing. Paper one investigated whether distraction by food-related stimuli

(and the associated attentional bias) would be modulated by perceptual load. This was a crucial first test of the perceptual load theory framework, as any immunity of food stimuli from perceptual load would significantly change subsequent hypotheses. At this stage, it was predicted that perceptual load would eliminate distraction by food stimuli. Participants completed a classic visual search manipulation of perceptual load, with food and non-food stimuli presented under low and high perceptual load. Additionally, as memory biases have been largely understudied in the literature, a memory test was included after the perceptual load task was completed. The first two experiments demonstrated that perceptual load reliably and powerfully eliminated distraction by food stimuli. There was no evidence of biased attention towards food above and beyond non-food stimuli, however, there was a biased memory recall of food compared to non-food stimuli. Therefore, in the third experiment, different distractor image sets were presented under low and high perceptual load. This allowed a test of whether perceptual load also eliminated the food memory bias, which the results confirmed. Finally, exploratory correlations were conducted between attention/memory to food stimuli and a set of individual difference traits identified from the literature to be implicated in cognitive processing of food. However, given the risk of false positives from examining multiple correlations in this manner, only correlations which replicated across multiple experiments were interpreted.

1.6.2. Paper two: A high perceptual load task reduces thoughts about chocolate, even while hungry.

Intrusive thoughts about food contribute to overeating by increasing craving. However, previous attempts to reduce them have been counter-productive or have often involved cognitively demanding strategies which can be difficult to maintain. Perceptual

load has been previously extended to internal thoughts and has been found to reduce thoughts unrelated to the task. Crucially, this is argued to occur in a passive and automatic manner. This study again used the classic visual search task, where participants reported their thoughts under low and high perceptual load. To increase the number of potential thoughts, prior to the task, participants held a chocolate bar in their hands and were instructed to focus on its sensory aspects before then being instructed to suppress any thoughts relating to the chocolate. Individual differences in state chocolate liking, craving and overall hunger were collected prior to the task. At the end of the experiment, participants completed a set of individual difference questionnaires. The interaction between both state and trait differences in regard to the effect of perceptual load on chocolate-related thoughts was explored. It was hypothesized that there would be less chocolate-related thoughts under high compared to low perceptual load. In addition, it was expected that any individual difference observed under low perceptual load, would not be found under high perceptual load.

1.6.3. Paper three: Flavour awareness is not reduced by perceptually demanding tasks: implications for ‘mindless’ eating.

Previous research has implicated lack of flavour awareness as a potential mechanism of inattentive eating (Braude & Stevenson, 2014; van der Wal & van Dillen, 2013). Paper three describes two experiments conducted to test whether perceptual load reduced awareness of flavour, and the associated increased intake. Participants were presented with palatable (salted) and unpalatable (unsalted) crisps while they simultaneously completed a low or high perceptual load task. Two measures of ‘flavour awareness’ were included. The first was reflected by the difference in intake of salted

compared to unsalted crisps (a palatability effect was expected under low and not high perceptual load). The second was taken from self-reported sensory ratings of the food (ratings were expected to be more distinct under low compared to high perceptual load). This was an important extension of perceptual load theory, as the task has rarely been applied to complex tasks such as consuming food. Experiment 1 found no evidence of reduced flavour awareness on either intake or self-reported measures. However, one potential explanation was that the task somehow interfered with intake in an unintentional way, even when perceptual demand was low. As this was the first test of perceptual load in an intake scenario, it was important to rule this out as a confound. In Experiment 2, the perceptual load task was altered so that a hand movement was not required to respond to the trials, and a no load control condition was added. Previously, the no load condition had not been included as low perceptual load is thought to be an active control condition which leaves attentional capacity freely available. There was no evidence to support this alternative explanation. As in previous papers, both the studies in Paper three included questionnaire measures of trait characteristics. The between-subjects design reduced our power to investigate individual differences, so instead questionnaire data was used to control for the effect of individual differences on intake.

1.6.4. Paper four: Ingested but not perceived: response to satiety cues eliminated by inattention

Satiety is known to be a strong determinant of intake. The final study tested the extent to which control of appetite is dependent on having available attention to process and respond to physiologically-derived internal cues, which have been traditionally considered to be underpinned by biological functions. The experiment incorporated the visual search

task into a typical preload design. Participants consumed a low energy thin texture or a high energy thick texture smoothie beverage, which was delivered via an intra-oral infusion device. This was to increase the level of experimental control over the rate and manner of consumption, which seemed particularly important given our difficulty observing any impact of perceptual load on intake in Paper three. During ingestion and for the thirty minutes after consumption (the period when satiety would normally develop) participants were continuously engaged in a task which placed either low or high demand on attention. Participants made several ratings regarding experienced satiety before and after the perceptual load task and were then given a 5 minute disguised taste test after all ratings had been completed. It was hypothesized that a typical ‘preload’ effect would be observed under low perceptual load: reflected by energy compensation and appropriate reduction in experienced satiety ratings after receiving the high energy thick texture beverage compared to the low energy thin texture beverage. However, both of these effects would be reduced when the beverages had been consumed under high perceptual load. Finally, the same set of questionnaire data was collected as in previous experiments, but only to ensure there were no unintentional group differences that could have affected the results.

2. Paper one: Testing a Load Theory framework for food-related cognition

Jenny Morris, Martin R. Yeomans and Sophie Forster

Abstract

The way we process rewarding stimuli is widely held to play a key role in normal and abnormal behaviour. Biased processing of food—arguably the most primal form of reward—has been strongly implicated in the obesity crisis. Paradoxically, however, existing evidence suggests that both too much and too little attention can potentially lead to overeating. Here we sought to explain this contradiction within the framework of the Load Theory of attention, while also elucidating the relatively understudied role of memory biases. In three experiments, we presented food and non-food images as irrelevant distractors during a letter search task with high and low levels of perceptual load, followed by a forced choice recognition task. As predicted, increasing perceptual load consistently powerfully reduced distraction by food and non-food images alike. Similarly, food images encountered under high perceptual load were less likely to be recognised in a surprise memory test. Unexpectedly, however, there was a striking absence of attentional bias to food above and beyond salient non-food stimuli, either within-subjects or in relation to traits implicated in food-biases. By contrast, a food memory bias was consistently observed across participants, and appeared independent of attentional biases. Food memory was consistently heightened in individuals with high levels of trait disinhibition (a measure of opportunistic eating). Our findings suggest that attention and memory for food and non-food are similarly impacted by perceptual load. We discuss implications of the Load theory framework for the wider literature on food-related cognition and for real world eating behaviours.

2.1. Introduction

Food is one of the most universal and powerful forms of reward, being both critical for survival and a potential source of pleasure. Like other forms of reward, the way we respond to food has a bidirectional relationship with basic cognitive processes such as attention and memory. On one hand, past experience with rewarding stimuli, such as food, can impact future cognitive processing (Anderson, Laurent & Yantis, 2013). For example, food associated with pleasant tastes are more likely to receive priority in cognitive processing (di Pellegrino, Magarelli & Mengarelli, 2011; Higgs, 2016). On the other hand, whether an individual over-eats is thought to be influenced by the way they attend and react to food cues (Werthmann, Jansen & Roefs, 2015). While some individuals can maintain a healthy weight, the obesity crisis is a growing concern due to the significant risk it poses to both physical and psychological health: an estimated 2.8 million people die every year due to the adverse consequences of being overweight or obese (World Health Organization, 2017). Given this, an important application of the rich cognitive psychology literature on attention and memory is to elucidate the mechanisms of over-eating and hence inform interventions.

Research on the cognitive mechanisms of over-eating has traditionally focused largely on attention, with more recent work also highlighting an important role for memory. However, as we will discuss in the following sections, the application of this large body of evidence to real world scenarios may be limited by seemingly contradictory implications of the literature. Namely, both too much and too little attention have both been suggested to result in overeating (Werthmann et al., 2015; Robinson et al., 2013). This complicates the advice that can be given to those trying to avoid over-eating, as it appears desirable to avoid

paying any attention to food in some situations, yet also important to give food our full attention in other situations. Here we argue that this contradiction may be explained utilising theories of attention to clearly differentiate between situations where increased attention can be a help or a hindrance.

Attentional processing of food

Food related attentional bias, the selective preferential processing of food cues, is one important aspect of biased cognition. Simply put, having an attentional bias for food increases the likelihood that you will notice food in the first place. Attentional bias to food has been typically measured by cognitive tasks showing either faster identification of a food target (e.g., an image of a food item) or interference with a task when a food stimulus was presented as the distractor. A multitude of studies have shown evidence for the presence of attentional bias for food stimuli (Ahern, Field, Yokum, Bohon & Stice, 2010; Castellanos et al., 2009; Cunningham & Egeth, 2018; Hollitt, Kemps, Tiggemann, Smeets & Mills, 2010; Meule, Vögele & Kübler, 2012; Neimeijer, de Jong & Roefs, 2013; Nijs, Muris, Euser & Franken, 2010; Seage, & Lee, 2017; Tapper, Pothos & Lawrence, 2010; Werthmann et al., 2011). There is also some evidence that this bias is heightened in individuals susceptible to overeating, such as those who are overweight (Werthmann et al., 2011; Hendrikse et al., 2015), people with a tendency towards dieting, (restrained eaters: Hollitt et al., 2010), people with a tendency towards uncontrolled eating (disinhibited eaters: Seage & Lee, 2017) and individuals with greater sensitivity to external food cues (external eaters: Brignell, Griffiths, Bradley & Mogg, 2009; Hou et al., 2011). However, we note that these individual differences findings have not always been replicated (e.g., Ahern et al., 2010; Boon, Vogelzang & Jansen, 2000; Doolan, Breslin, Hanna & Gallagher, 2015;

Freijy, Mullan & Sharpe, 2014; Loeber et al., 2012; Nijs et al., 2010; Pothos, Tapper & Calitri, 2009; Werthmann et al., 2013; Werthmann et al., 2011).

Attentional bias towards food is argued to have been evolutionarily advantageous, in terms of facilitating the seeking and finding of food in our environment (Werthmann et al., 2015). However, in our modern obesogenic environment attentional bias is thought to be maladaptive and has been associated with several aspects of eating behaviour such as craving, consumption (Werthmann, Field, Roefs, Nederkoorn & Jansen, 2014) and weight gain (Yokum, Ng & Stice, 2011).

While overly attending to food cues is thought to contribute towards over-eating, studies examining attention during ingestion find the opposite effect. Inattentive eating is associated with increased consumption (see Robinson et al., 2013 for a recent review). This is typically tested by comparing amount consumed while attention is engaged in a task such as a game, television, radio or reading to amount consumed with no task. Several mechanisms have been put forward to explain the inattentive over-eating effect including reduced awareness of intake, interoceptive signals and dietary control (Braude & Stevenson, 2014). It might simply be assumed that the effect of attention to food cues depends on the stage of eating, with attention to food cues prior to ingestion increasing the likelihood of food being consumed; and attention during ingestion decreasing the quantity that is consumed. However, as outlined below, the paradigms that have been used to study attentional bias and inattentive eating also differ in terms of a factor that has been highlighted within the selective attention literature as a powerful determinant of attention: perceptual load.

A large body of evidence in support of the Load Theory of attention (e.g., Lavie, 2005; 2010) highlights that the extent to which task-irrelevant stimuli are processed depends on whether the current task leaves sufficient spare perceptual capacity. If the perceptual demand (or ‘load’) of the task is high (e.g., searching for a friend in a crowded restaurant), task-related processing exhausts perceptual capacity with the result that task-irrelevant stimuli are not processed. On the other hand, when demand is low (e.g., searching for a friend in an empty restaurant) sufficient capacity remains to process task-irrelevant stimuli (e.g., a ringing phone, or the drinks at the bar). Importantly, the modulation of attention by perceptual load is argued to occur in a passive and automatic manner.

Applying the Load Theory framework to eating behaviour plausibly accommodates existing evidence and allows more nuanced predictions and recommendations for real world situations. If perceptual load modulates processing of food stimuli in the same manner as other stimuli, it would be expected that attentional biases and inattentive eating would be observed in distinct situations. Vulnerability to attentional biases (and the resulting increased consumption) should be associated primarily with conditions of low perceptual load, when the current task leaves sufficient spare capacity to allow irrelevant food cues to catch our attention. For example, we might be more likely to notice the dessert trolley while searching for our friend in an empty restaurant versus a crowded restaurant. On the other hand, vulnerability to inattentive eating should occur only in conditions of high perceptual load, when attentional capacity is exhausted by the task. Going back to our restaurant example, imagine that we begin eating while still keeping an eye out for our late-arriving friend: the undemanding task of monitoring the empty restaurant would

theoretically be beneficial here in terms of leaving sufficient capacity for awareness of interoceptive signals, making it less likely that we would unintentionally over-indulge. Consistent with our proposed application of Load Theory, the majority of evidence for food-related attentional bias rests on perceptually undemanding tasks such as the visual probe, in which only a small amount of information must be processed at any given time, while inattentive eating studies typically use more perceptually demanding tasks such as computer games and television (Robinson et al., 2013).

Load Theory provides a useful framework from which to draw practical recommendations. Rather than advising individuals to simply attempt to ignore food at all times other than when they are eating, which would place high demands on effortful goal maintenance and inhibitory processes, the Load Theory framework implies that individuals could simply organise their daily tasks in such a way as to passively facilitate beneficial eating behaviours. For example, individuals wishing to avoid over-eating might find high perceptual load tasks useful in avoiding temptation in the course of their daily lives but would be advised to engage only in less demanding tasks while they are eating.

Our proposed application of Load Theory to food-related cognition assumes that perceptual load would modulate food cues in the same manner as non-food stimuli. However, this key assumption is brought into question by a recent study in which several other categories of rewarding stimuli (happy faces, erotic images and stimuli associated with money) caused distractor interference even under high perceptual load (Gupta, Hur & Lavie, 2016), suggesting that rewarding stimuli may be among the ‘special’ stimulus categories immune to perceptual load effects. Hence, a critical first step in applying the Load Theory framework was to establish whether external food cues would be modulated

by load in the same manner as non-food cues, or whether the rewarding properties of food would render it immune to load effects. Here we tested this possibility by, for the first time, comparing attention to food and non-food stimuli in situations of high versus low perceptual load. If our account is correct, food stimuli should be more likely to attract attention during low perceptual load conditions. When perceptual load is increased, attentional processing of food stimuli (and hence any attentional bias) should be reduced or even eliminated.

The role of memory.

The effects of perceptual load have also been found to extend beyond attention, to impede memory for stimuli encountered under high perceptual load (Jenkins, Lavie & Driver, 2005). This raises the intriguing possibility that perceptual load might impact eating behaviour beyond the time point that the stimulus is originally encountered, by modulating the likelihood that a food cue will be later recognised. The mechanism by which attentional biases lead to later consumption necessarily involves memory for the food cue. For example, May, Andrade, Kavanagh & Hetherington (2012) suggest that once a food cue captures attention it is then more likely to be processed further and remembered, reducing an individual's ability to ignore that craving. Perceptual load could therefore potentially not only reduce the likelihood of food cues capturing attention in the first place, but also disrupt the pathway from capture to craving (and ultimately over-eating) by preventing the food cues from being encoded into memory.

The above suggestion implies a benefit of perceptual load-disrupted memory in avoiding over-eating. However, as in the case of inattentive eating, a high perceptual load task during ingestion could have the opposite consequence. If, as we predict, perceptual

load impedes memory for food-related stimuli this would also imply that engaging in a high perceptual load task while eating might interfere with people's ability to later remember how much they have eaten. This would be undesirable given that memory for previous intake appears to play an important role in eating behaviour, as shown by research with amnesic patients who despite consuming multiple meals show no changes in reported hunger (Hebben, Corkin, Eichenbaum, Shedlack, 1985; Rozin, Dow, Moscovitch & Rajaram, 1998). In healthy participants, poor memory for a recent meal, usually manipulated by disrupting the encoding of the meal via a secondary task, has been repeatedly shown to increase subsequent intake (Higgs, 2015; Mittal, Stevenson, Oaten & Miller, 2011; Moray, Fu, Brill, & Mayoral, 2007; Oldham-Cooper, Hardman, Nicoll, Rogers, & Brunstrom, 2010). Notably, as with the inattentive eating literature, the secondary tasks used to demonstrate memory effects on eating behaviour are typically rather perceptually demanding tasks such as computer games (Higgs, 2015; Oldham-Cooper et al., 2010) or television (Higgs, 2015; Moray et al., 2007; Mittal et al., 2011). Our study therefore sought to more directly test the possibility that high perceptual load tasks can interfere with memory for food cues.

Just as the effect of memory on intake parallels the inattentive eating literature, a small number of studies demonstrate memory effects paralleling the attentional bias literature. Biased memory for food has been found using recognition memory tests in hungry participants (Morris & Dolan, 2001) and with free recall tasks in both hungry (Talmi et al, 2013) and restrained eaters (Soetens, Roets & Raes, 2014). A significant theoretical question is to what extent the roles of attention and memory on eating

behaviours are separable. Are the effects of poor memory on over-consumption and enhanced memory for food stimuli simply a consequence of attentional processes?

It is well established that disrupting attention at the time of encoding is detrimental to subsequent memory performance (Anderson & Craik, 1974; Baddeley, Lewis, Eldridge, & Thomson, 1984; Jenkins et al., 2005). Similarly, the elaboration intrusion theory (May et al., 2012) from the eating literature argues that food attentional bias leads to cognitive elaboration of food related cues, their consequent presence in working memory should make them easier to remember, hence memory bias reflects the early attention bias. On the other hand, the relationship between attention and memory is bidirectional: memory has also been found to guide attention. For example, Rutters, Kumar, Higgs & Hunphreys (2014) found with both behavioural and electrophysiological measures that holding food cues in working memory guided attention towards task irrelevant food distractor images. More broadly, it should be noted that memory plays a key role in eating behaviour, through the learning of associations between food cues, eating and its consequences (see Higgs, 2016, for a full review on the role of memory). For example, flavour aversions may be learnt from a previous pairing of the flavour and a negative post-ingestive consequence (i.e., illness); future food choices and intake is then guided by this learned association (Garcia & Koelling, 1966; Smith and Roll, 1967).

To date only one study has attempted to compare both attention and memory biases to food; Talmi and colleagues (2013) measured interference from food images on a tone discrimination task, followed by a free recall memory test. Although they found both attention and memory biases in participants under conditions of hunger, but not satiety, these processes did not appear to be linked. This intriguing null result is at odds with the

wider attention and memory literature. A secondary aim of our study is therefore to more extensively test the relationship between attention and memory.

The current research.

In summary, the current research provides the first test of an application of the Load Theory framework to understand the influence of basic cognitive processes (attention and memory) on eating behaviours. Across three experiments we conducted a comprehensive investigation of both attention and memory biases across a single paradigm based on the irrelevant distractor task (Forster & Lavie, 2008). This task has previously been adapted, using a well-established manipulation of perceptual load, to replicate the effects of perceptual load on task irrelevant processing (Forster & Lavie, 2008; 2016; Lancaster, Forster, Tabet & Rusted, 2017; Lunn, Sjoblom, Ward, Soto-Faraco & Forster, 2019). A version of this task, which did not include a perceptual load manipulation, was also recently used to demonstrate the attentional bias for food cues (Cunningham & Egeth, 2018). The irrelevant distractor task has the advantage that, unlike widely used measures such as the dot-probe, the distractor is presented in an entirely task irrelevant location and as such avoids inadvertently encouraging top down attention to food (for further discussion of this issue see Forster & Lavie, 2008; Lichtenstein-Vidne, Henik & Safadi, 2007). Hence, distractor interference in this task is analogous to the daily life phenomenon whereby attention is drawn to something entirely irrelevant to what we are currently doing—for example, as we sit on a train reading a book, an advert for a chocolate bar might catch our eye.

Our first aim across all experiments was to establish whether the powerful effects of perceptual load in reducing task irrelevant processing also extend to food stimuli; this

would be reflected by slower reaction times on food present trials compared to no distractor trials under low perceptual load but no difference under high perceptual load. We also tested whether a memory bias exists for food images, which would be demonstrated by higher recognition accuracy of food images compared to non-food images on a recognition memory task. We expected this memory bias to manifest only under low perceptual load conditions—this was tested directly in our final experiment.

To investigate the extent to which attention and memory biases (and their modulation by perceptual load) are related, we examined the correlation between attention and memory biases in each of our experiments. If a memory bias is a consequence of the attentional bias, it would follow that a stronger attentional bias in an individual would lead to a stronger memory bias. Similarly, if load modulation of memory for food cues reflects the load effect on attention, the degree of the load effect on memory should be greatest for those participants showing the greatest load effect on attention. Finally, we also measured a variety of traits previously shown to influence food related cognition to enable exploratory analyses of potential interactions of trait differences and perceptual load.

2.2. Experiment 1

2.2.1. Method

Participants. 60 female participants aged between 18-35 years ($M = 21.46$, $SD = 1.68$), with normal or corrected to normal (e.g., with glasses) vision, who were either native English speakers or as fluent at both speaking and reading English as a native speaker. Three participants were excluded from analysis as it was later identified they did not meet all the eligibility requirements. Participants were primarily University of Sussex students who received course credit or a five-pound financial compensation.

Forster and Lavie's 2016 study, which replicated the load effects on irrelevant distraction in a sample size of 77, found an effect size of .36 for the interaction of load and distractor interference. A more recent study using the irrelevant distractor paradigm, in a very similar design to our study (2 x 3 within-subjects), found an effect size of .10 for the interaction between load and distractor interference, in a sample size of 52 (Lunn et al., 2019). Our sample size of 60 was selected apriori on the basis of being highly powered (.95) to detect the within subject effects reported by Lunn and colleagues (2019) and having 80% power to detect small-medium correlations of .33 (Faul, Erdfelder, lang & Buchner, 2007). The study was approved by the University of Sussex Sciences & Technology Cross-Schools Research Ethics Committee and complied fully with BPS ethical standards.

Stimuli and procedure. The task was adapted from Forster & Lavie's (2008) irrelevant distractor paradigm. All stimuli were presented using E-prime 2.0 (Schneider, Eschman & Zuccolotto, 2002) on a 13.5 inch computer screen at a viewing distance of

57cm. The experiment was presented on a black background and all letter stimuli were grey.

At the start of every trial a fixation point appeared for 500ms, followed by the stimulus display. When the stimulus display appeared, participants had to search for an 'X' or 'N' target letter which appeared in a random location within a circle of six letters (see Figure 1). In the high load condition the nontarget letters in the circle were selected at random from five potential letters: H, K, M, Z, W, V. In the low load condition, the nontarget letters were all lower-case o's. The letter circle had a 2.4° radius (each letter subtending 1.2° by 1°) and the small o's were 0.19° . The letter stimuli appeared for 100ms, but participants had up to 2000ms to respond.

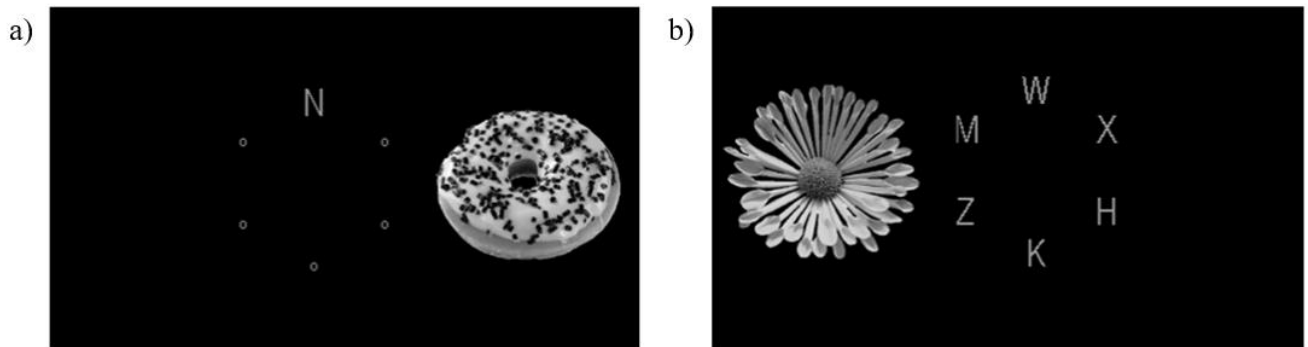


Figure 1. Example stimulus displays with: (a) a food distractor presented on a low load trial, (b) a non-food (nature) distractor presented on a high load trial. Food/non-food distractors appeared with equal frequency in the high and low load conditions. Participants searched for the target letter (X or N), while ignoring any distractors.

The majority of trials did not contain a distractor (80%); the remaining trials contained a distractor image. On 10% of trials a randomly selected image of a sweet food item was presented (six food stimuli were used: doughnut, chocolate bar, chocolate cake,

muffins, ice cream or a cookie). On another 10% of trials a randomly selected non-food item was presented (six non-food stimuli were used: pink flower, yellow flower, white flower, red leaf, orange leaf or green leaf). Each stimulus was presented once in each block and a total of eight times throughout the visual search task. Distractor stimuli were presented at a peripheral location, left or right of the letter circle. Distractor stimuli subtended 3.4° to 4.9° vertically by 3.2° to 4.9° horizontally. The centre of the distractor was 4.6° from fixation and between 0.6° and 1° edge to edge from the nearest stimulus. The distractor was equally likely to appear in either of these locations. The distractor remained on screen until response or timeout at 2000ms. Both food and non-food stimuli were selected from the online image database “food-pics” (Blechert et al., 2014) – each image in this database has been rated by 1988 people on a range of visual and affective features. The six food images and six non-food images that we selected did not differ on measures of valence, arousal, brightness, contrast, complexity or familiarity (all $ps > .127$, see table S1 for means). Food images were chosen based on those which had high palatability and craving ratings.

Participants completed three slow example trials (stimuli appeared for 2000ms) and 12 practice trials for both low and high load displays. No distractors appeared during the practice trials. Participants then completed eight experimental blocks, four low load and four high load, each block contained 60 trials. As in Forster & Lavie’s (2008) experiments, blocks were counterbalanced across participants in the following order: LHHLLHHL or HLLHHLLH. Within each block, all combinations of load, target position, target identity, distractor condition and distractor identity were counterbalanced. Distractor images did not appear on the first three trials in each block and these trials were excluded from analysis.

Following the visual search portion of the experiment participants completed a surprise memory test for the distractor images used in the task. Each distractor image was presented alongside two novel but similar images of the same item (i.e., cookie); participants made a forced choice of which image they had previously seen in the experiment (see Figure 2). Location of correct image and corresponding correct keyboard response were randomised.

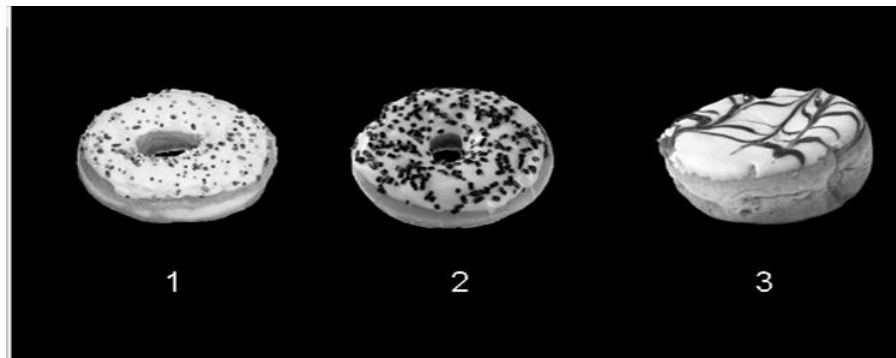


Figure 2. Forced choice memory test. Participants were asked to identify the stimulus presented during the visual search task.

Following the memory test, participants completed several ratings. Hunger was measured using a 0-100 visual analogue scale (VAS), embedded within nine other irrelevant mood ratings. We were interested in hunger as it had previously been linked to attentional bias for food stimuli (Castellanos et al., 2009; Nijs et al., 2010; Tapper et al., 2010); the nine other ratings were intended to disguise the hunger rating and received no further analysis. Each VAS scale was presented as a 100mm horizontal line on the computer screen. Each mood question appeared above the line with a lower end anchor of ‘Not at all’ and an upper end anchor of ‘Extremely’. Participants dragged the cursor from the midpoint of the scale to indicate their current mood. Sussex Ingestion Pattern Monitor

(SIPM: University of Sussex; Yeomans, 2000) was used to collect these ratings. Hunger was not explicitly manipulated, instead participants were tested between 10.00-12.00 am and 3.00-5.00pm. All testing was carried out in experimental cubicles at the University of Sussex Ingestive behaviour laboratory.

Finally, participants completed a set of questionnaires measuring individual difference characteristics. The researcher also measured participant's height and weight at the end of the experiment using a stadiometer with an integrated height measure, before thanking and debriefing them. Height and weight were used to calculate body mass index (BMI).

Questionnaire measures. We conducted a search of the attentional bias literature to identify questionnaire measures thought to measure separate constructs and which would be predicted to influence attention to food stimuli. Individual difference measures were chosen based on their relevance to eating behaviour and frequency of use within attentional bias studies.

Measures of eating attitude.

Three Factor Eating Questionnaire (TFEQ; Stunkard & Messick, 1985). The 51 item TFEQ is divided into three factors; restraint, disinhibition and hunger. Several studies have linked both restraint (Ahern et al., 2010; Castellanos et al., 2009; Hollitt et al., 2010; Neimeijer et al., 2013) and disinhibition (Castellanos et al., 2009; Seage & Lee, 2017) with biased attention towards food stimuli. However, it should be noted the relationship between TFEQ and attention to food is not always observed, particularly on reaction time measures (Werthmann et al., 2013).

Dutch Eating Behaviour Questionnaire (DEBQ; Van Strien, Frijters, Bergers & Defares, 1986). Only the 10-item external eating subscale of the DEBQ was used in this experiment, as it is thought to be the most directly relevant to attentional bias (Brignell et al., 2009; Hou et al., 2011). With some exceptions on reaction time measures (Nijs, Muris, Euser & Franken, 2010), external eating has been linked to biased attention for food stimuli (Brignell et al., 2009; Hou et al., 2011).

Measures of impulsiveness.

Barratt Impulsiveness Scale (BIS 11; Patton, et al, 1995). The 30 item BIS 11 measures three dimensions of impulsivity: attentional, motor and non-planning. The BIS 11 has been found to correlate with attentional bias to food (Lattimore & Read, 2015; Meule & Platte, 2016), even after controlling for external eating (Hou et al., 2011).

Sensitivity to punishment and reward Questionnaire (SPSRQ; Torrubia, Avila, Moltó, & Caseras, 2001). This 48-item questionnaire comprised of two subscales, sensitivity to reward (SR) which reflects behavioural activation and the sensitivity to punishment which reflects behavioural inhibition. Sensitivity to reward has been associated with greater attention to food (Hennegan, Loxton & Mattar, 2013).

2.2.2. Results

Traditional analyses for all three experiments were conducted using IBM SPSS Statistics 24. Data for all experiments can be downloaded from the Open Science Framework (<https://osf.io/srehg/>).

Reaction times. To test whether attention to food was modulated by load, we calculated mean reaction times (RT) on correct response trials only, and then contrasted these as a function of load (low, high) and distractor condition (food, non-food, absent) using a 2 x 3 within-subject ANOVA. Table 1 presents mean RTs, accuracy and distractor costs across different conditions. Distractor costs were calculated by subtracting the RT when no distractor was present from the RT when a distractor was present: this demonstrates the cost to RT when a particular distractor is present. We used distractor costs as our measure of attentional processing (as in Forster & Lavie, 2008). The difference between food and non-food distractor costs is our measure of attentional bias.

Table 1

Mean RT's (SE in parentheses) and percentage accuracy rates across different distractor conditions under low and high load in Experiment 1.

	Distractor condition			Distractor costs	
	F	NF	ND	F-ND	NF-ND
Low load					
RT (ms)	491 (9)	494 (8)	474 (8)	17	20
% error	15	16	16		
High load					
RT (ms)	701 (15)	709 (16)	706 (16)	-5	3
% error	28	31	28		

Note. F= food distractor, NF= non-food distractor, ND= no distractor, F-ND= food distractor cost, NF-ND = non-food distractor cost.

As predicted, RTs were slower overall on high than low load trials, $F(1, 56) = 294.77, p < .001, N_p^2 = .84$, confirming that the load manipulation increased task difficulty. There was a significant main effect of distractor type, $F(2, 112) = 3.57, p = .039, N_p^2 = .06$, with greenhouse geisser correction applied as Mauchly's test suggests sphericity was violated for the interaction, $X^2(2) = 10.57, p = .005$. Critically, the interaction between load and distractor was also significant, $F(2, 112) = 3.71, p = .037, N_p^2 = .06$, greenhouse geisser correction applied for violated sphericity, $X^2(2) = 14.99, p < .001$. The significant interaction reflects that the distractor costs from both food and non-food stimuli were observed under low load, but not under high load (see Table 1).

To investigate the significant interaction, we conducted planned contrasts on two separate one way ANOVA's: one for the three distractor conditions under low load and

another for the same variables under high load. There was a significant effect of distractor under low load, $F(1, 56) = 7.59, p = .008, N_p^2 = .12$, but not under high load, $F(1, 56) = .44, p = .511, N_p^2 = .01$.

As there was a significant effect of distractor under low load, we conducted follow up *t*-tests. Under low load RTs were significantly slower when a food distractor was present, $t(56) = 3.66, p = .001, d = .28$, and when a non-food distractor was present, $t(56) = 5.49, p < .001, d = .33$, compared to when no distractor was present. Unexpectedly, across all participants, under low load there was no evidence of attentional bias to food distractors: RT did not differ in the presence of food versus non-food distractors, $t(56) = .43, p = .672, d = .04$.

Error rates. While RT is the primary measure of interest, a 2x3 within subject ANOVA was applied to the equivalent percentage error data (error referring to a missed or incorrect keyboard response to the letter search task). There was a significant main effect of load, $F(1, 56) = 83.13, p < .001, N_p^2 = .60$, reflecting higher error rates under high load compared to low load. Neither the main effect of distractor nor the load by distractor interaction reached significance (all *ps* > .2).

Recognition accuracy for images. A within subjects *t*-test was used to compare the number of food and non-food images recognised on the memory test. Despite no attentional bias to food images being observed, a significant memory bias was found: As can be seen (Figure 3), the mean percentage recognition accuracy was greater for food images than non-food images, $t(56) = 2.43, p = .019, d = .45$.

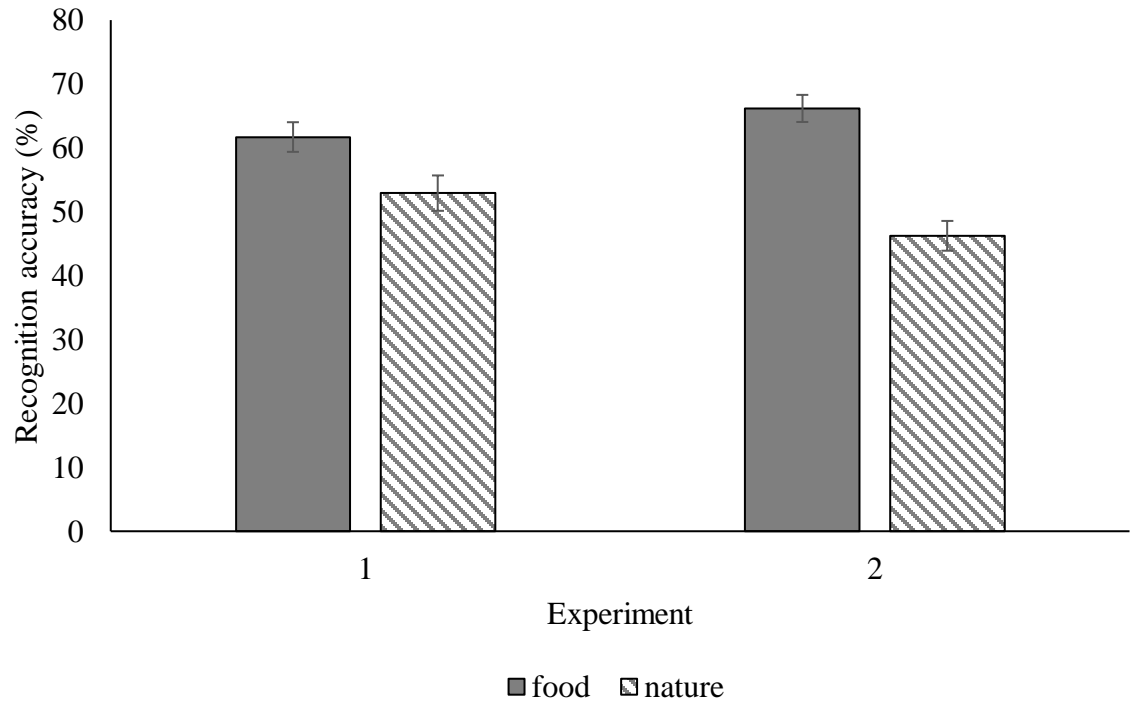


Figure 3. Mean recognition accuracy for food and non-food images across Experiments 1 (left) and 2 (right). Experiments 1 and 2 were identical, with the exception of stimuli location (Experiment 1: periphery; Experiment 2: fixation).

Individual differences in food-related attention and memory. We also examined whether individual differences in recognition accuracy of food items was related to the extent to which people were distracted by these stimuli during the visual search task. Increased memory for the distractor stimuli was not associated with an increased distractor cost for the corresponding stimuli for both food, $r(55) = -.02$, $p = .437$, 95% CIs, [-.28, .21], and non-food categories, $r(55) = .16$, $p = .124$, 95% CIs, [-.10, .35]. In addition, attentional bias for food stimuli was not correlated with memory bias for food, $r(55) = -.03$, $p = .409$, 95% CIs, [-.34, .22]. Therefore, the memory bias did not appear to be dependent on attention.

Exploratory analysis of individual differences. We also conducted a range of exploratory correlations to analyse individual differences in Experiment 1 due to the variety of measures used in the literature. For the full set of correlations see Table S2 in the Supplemental Material. Following the advice of Field (2012) Bonferroni corrections have not been applied, instead correlations have been reported with their bootstrapped confidence intervals.

Only one significant correlation was found between the effect of the presence of distracting images on performance on the visual search task and any of the questionnaire measures of eating and impulsivity: participants scoring highly on the TFEQ restraint scale were more distracted by food, $r(55) = .29, p = .014$, 95% CIs, $[-.02, .51]$, but not non-food stimuli, $r(55) = .16, p = .124$, 95% CIs, $[-.09, .42]$, under low load, although the difference for food vs non-food distraction (i.e., the attentional bias) did not reach significance, $r(55) = .15, p = .136$, 95% CIs, $[-.16, .40]$. In addition, none of the questionnaire measures correlated with the load modulation (distraction under low load – distraction under high load) of distraction by food images, all $ps > .1$.

On the other hand, recognition accuracy for food correlated with a set of measures relating to the tendency to over-eat: higher trait TFEQ disinhibition, $r(55) = .25, p = .033$, 95% CIs, $[-.08, .52]$, and BMI, $r(55) = .33, p = .006$, 95% CIs, $[-.15, .53]$, positively predicted the number of food images recognised in the memory test, with self-rated hunger showing a similar but marginally significant relationship, $r(55) = .21, p = .060$, 95% CIs, $[-.09, .48]$. None of these measures were associated with recognition of non-food images, all $ps > .13$. Unlike disinhibition and BMI, all $ps > .11$, self-rated hunger also correlated

significantly with memory bias for food images (i.e., the degree of increased recognition accuracy for food versus non-food images), $r(55) = .25$, $p = .031$, 95% CIs, [-.06, .52].

2.2.3. Discussion

The key finding from Experiment 1 is that distraction by food stimuli was eliminated in the high load condition, thus supporting our prediction that food cues can be modulated by perceptual load in the same manner as non-food stimuli. Therefore, contrary to studies which have suggested that positive stimuli may be immune to the effects of perceptual load (Gupta, Hur & Lavie, 2016), food does not constitute a ‘special’ load-resistant stimulus category. An unexpected finding of Experiment 1 was the absence of heightened distraction for food versus non-food stimuli (i.e., attentional bias). As such, our results suggest cannot speak to the issue of how load would affect any such bias. Nevertheless, our findings are compatible with our proposed application of the Load Theory framework to cognitive processing of food, in terms of implying that the likelihood of external food cues catching our attention, potentially triggering overeating, is substantially greater in situations of low perceptual load.

Despite not finding an attentional bias, we did find a clear memory bias for food. This is the first demonstration, to our knowledge, of a general memory bias for food across individuals. The presence of this bias in the absence of any attentional bias, in addition to the lack of correlation between attentional and memory biases, is intriguing in suggesting that food cues may receive prioritised processing at some stage of memory independently of attention.

Regarding our exploratory analysis, perhaps the most striking result was the absence of any correlation between attentional bias and the trait measures that have been previously linked to eating behaviours. In the light of this finding, it appears unlikely that the lack of

overall bias could be explained by the trait composition of our sample. While a small number of potentially intriguing correlations were observed, particularly with respect to memory, given the high risk of false positives due to over-testing we sought to determine whether these could be replicated in subsequent experiments.

2.3. Experiment 2

Experiment 1 demonstrated that food stimuli are modulated by perceptual load to the same extent as non-food stimuli, thereby providing initial support for our proposal that Load Theory can be applied to food-related cognition. We also found evidence of a memory bias which did not appear to be linked to attention. Unexpectedly, however, no attentional bias to food stimuli was observed in either load condition. We reasoned that one potential explanation for the lack of attentional bias could be our presentation of food stimuli in entirely task-irrelevant locations. As mentioned in our introduction, previous evidence for attentional food bias has almost exclusively been found using paradigms such as the dot probe, in which the distractor location must be attended (although see Cunningham & Egeth, 2018, for a recent exception published after we had collected this data). To explore this possibility, Experiment 2 repeated the methods of Experiment 1 using distractors presented at fixation. This also afforded an opportunity to internally replicate our findings regarding load modulation of food distractors and a memory bias to food images

An additional aim of Experiment 2 was to test whether the correlations revealed in the exploratory analysis of Experiment 1 would replicate. In particular we wanted to test whether significant relationships would be found, as in Experiment 1, between memory of food and a cluster of traits linked to over-eating: disinhibition, hunger, BMI.

2.3.1. Method

Participants. One-hundred and two female participants aged between 18-35 years ($M = 21.09$, $SD = 3.26$), all other participant details were identical to Experiment 1. For Experiment 2 and 3 we increased the sample size to one-hundred (two extra participants were recruited due to scheduling issues) to detect smaller correlations. According to G*Power, this sample size allowed us to detect a correlation of .25 with 80% power (Faul, Erdfelder, Lang & Buchner, 2007).

Stimuli and Procedure. All stimuli and procedure were identical to Experiment 1, except for the distractor stimuli location and size. All distractor stimuli were presented at fixation, at the centre of the letter circle. Due to better retinal acuity at central locations, the distractor images were reduced to ensure their cortical representation was equivalent to those in Experiment 1. We used the cortical magnification equation provided by Rousselet, Husk, Bennett & Sekuler (2005) to obtain a scaling factor of 2.43. After using the scaling factor to reduce the size of distractor stimuli, they subtended 1.4° to 2° vertically by 1.3° to 2° horizontally.

2.3.2. Results

Reaction times. As in Experiment 1, to test the primary hypothesis that load would modulate distraction by food stimuli, RTs (correct responses only) were entered into a 2 x 3 within-subject ANOVA, with the factors of load (low, high) and distractor type (food, non-food, absent). Table 2 presents mean RTs, accuracy and distractor costs across different conditions.

Table 2

Mean RTs (SE in parentheses) and percentage accuracy rates across different distractor conditions under low and high load in Experiment 2.

	Distractor condition			Distractor costs	
	F	NF	ND	F-ND	NF-ND
Low load					
RT (ms)	560 (8)	563 (8)	528 (7)	31	35
% error	12	13	10		
High load					
RT (ms)	785 (12)	781 (12)	794 (12)	-10	-14
% error	26	27	22		

Note. F= food distractor, NF= non-food distractor, ND= no distractor, F-ND= food distractor cost, NF-ND = non-food distractor cost.

The main effects of load, distractor and the load x distractor interaction were replicated from Experiment 1. The load x distractor type ANOVA showed a significant main effect of load, $F(1, 101) = 587.99, p < .001, N_p^2 = .85$: RTs were longer in the high load than in the low load conditions, confirming that the load manipulation increased the task difficulty. There was also a significant main effect of distractor type, $F(2, 202) = 5.10$,

$p = .007$, $N_p^2 = .05$: RT's were slower for both food and non-food distractor present trials compared to no distractor trials. Finally, there was a significant load x distractor interaction, $F(2, 202) = 24.00$, $p < .001$, $N_p^2 = .19$. Greenhouse geisser correction was applied as Mauchly's test suggested sphericity was violated for this interaction, $X^2(2) = 18.29$, $p < .001$.

As in Experiment 1, we investigated the significant interaction with planned contrasts on distractor type under each level of load. Under low load there was a significant effect of distractor, $F(1, 101) = 33.27$, $p < .001$, $N_p^2 = .25$, but not under high load, $F(1, 101) = 1.86$, $p = .175$, $N_p^2 = .02$. This suggests that high load eliminated distractor interference.

Follow up t -tests suggest under low load RT's were significantly slower both when a food distractor was present, $t(101) = 8.38$, $p < .001$, $d = .40$, and when a non-food distractor was present, $t(101) = 9.70$, $p < .001$, $d = .46$, versus the no distractor baseline. However, critically, as in our previous experiment there was no significant difference on RT between food and non-food distractors, $t(101) = .84$, $p = .401$, $d = .04$. Hence, even when presented at fixation food distractors did not appear to differentially capture attention.

Error rates. A 2x3 within subject ANOVA was applied to the equivalent error data. There was a significant main effect of load, $F(1, 101) = 198.94$, $p < .001$. $N_p^2 = .66$, again showing higher error rates under high compared to low load. Unlike Experiment 1, there was also a significant main effect of distractor, $F(2, 202) = 14.89$, $p < .001$, $N_p^2 = .13$, reflecting higher error rates on both food and control distractor present trials compared to distractor absent trials. Greenhouse geisser applied due to violated sphericity $X^2(2) = 18.96$, $p < .001$. The interaction was not significant $p > .2$.

Recognition accuracy for images. Mean number of images recognised are presented in Figure 3. As in Experiment 1, a within subjects *t*-test showed that participants recognised significantly more food images than non-food images, $t(101) = 7.50, p < .001, d = .89$. This finding suggests participants displayed a memory bias towards food stimuli.

Individual differences in food-related attention and memory. Increased recognition accuracy for the distractor stimuli was not associated with an increased distractor cost for the corresponding stimulus for both food, $r(100) = -.05, p = .309$, 95% CIs, $[-.22, .11]$, and non-food categories, $r(100) = .15, p = .068$, 95% CIs, $[-.04, .33]$. In addition, the correlation between attentional and memory bias for food stimuli was not significant, $r(100) = -.14, p = .078$, 95% CIs, $[-.31, .03]$. This is in line with the null findings from Experiment 1 and does not support any link between attention and memory biases in this context.

The role of individual differences. The full set of correlations between attention, memory and individual differences are presented in Table S3 of the Supplementary Materials. The correlations previously observed between recognition accuracy of food stimuli and disinhibition, hunger and BMI were replicated in Experiment 2: disinhibition, $r(100) = .18, p = .036$, 95% CIs, $[-.02, .35]$; hunger, $r(100) = .20, p = .023$, 95% CIs, $[-.01, .40]$; and BMI, $r(100) = .24, p = .008$, 95% CIs, $[-.06, .41]$. Specifically, all three measures significantly and positively predicted the number of food images recognised in the memory test, but not the number of non-food images recognised, all $ps > .17$. In Experiment 1, hunger was also associated with a memory bias for food, but this correlation did not reach significance in Experiment 2, $r(100) = .11, p = .127$, 95% CIs, $[-.08, .30]$.

The exploratory finding of a correlation between restraint and food-related distraction under low load did not replicate in Experiment 2, $r(100) = .01$, $p = .48$, 95% CIs $[-.21, .21]$, suggesting that it may have been a false positive.

2.3.3. Discussion

Experiment 2 replicated our key finding that the processing of food cues can be modulated by perceptual load in the same manner as non-food stimuli. Indeed, it was striking that perceptual load completely eliminated any interference from food and non-food distractors alike, even when these were presented at fixation. We also replicated the memory bias for food across participants, as well as our exploratory finding of enhanced memory for food among individuals with high levels of food disinhibition, hunger and BMI. However, as in Experiment 1, memory for food did not appear related to any attention measure.

Despite our presentation of the distractors at fixation, no attentional bias for food stimuli was observed—rather, food and non-food stimuli were equally distracting. In both Experiments 1 and 2 we used natural stimuli (flowers and leaves) as the non-food control category, they were matched to the food stimuli in both valence and arousal. We chose a positively valenced control category so that any potential ‘special’ attention grabbing properties of food could be attributed specifically to food and not to just positive stimuli in general. Previous attentional bias research, while controlling for low level visual differences, does not usually control for valence and arousal differences between their food and control stimulus sets. The lack of attentional bias in Experiments 1 and 2 might therefore be explained by our choice of control stimuli. For this reason, our final experiment used a neutral control category more consistent with prior literature; we chose office equipment as they have been frequently used as a control category in previous studies investigating cognitive processing (Hume, Howells, Rauch, Kroff & Lambert, 2015;

Nijs, Franken & Muris, 2008; Nijs et al., 2010; Svaldi et al., 2015; Velázquez-Martínez, Toscano-Zapién & Velázquez-López, 2013).

Using office equipment as distractors also allowed us to address an issue relating to the food memory bias revealed in Experiments 1 and 2. Our food and non-food distractor stimuli were matched on several variables (valence, arousal, brightness, contrast and complexity) and were selected to be visually distinctive from other distractors in the same condition (e.g., the flower stimuli consisted of a pink, yellow and a white flower). However, the food category consisted of six nameable stimuli, whereas the non-food category consisted of only two. It is not clear what effect this might have on memory. On one hand it could be argued that the ability to name all six food stimuli made them more distinctive. On the other hand, as the memory test involved identifying the distractor images among other items from same category (e.g., a doughnut among other doughnuts), the use of multiple exemplars from the same category might have highlighted within category visual differences and hence facilitated memory for the non-food images. In order to rule out any potential influence of namability, the office stimuli chosen for Experiment 3 were distinct items that could be easily named.

2.4. Experiment 3

Experiments 1 and 2 provide strong evidence to suggest that perceptual load can modulate the extent to which food cues are processed, to the extent that they do not produce reaction time interference even when directly fixated. In this respect, the effects of perceptual load on food cues were similar to those observed for non-food cues. This evidence is compatible with our application of a Load Theory framework to food-related attentional processing. In our previous experiments, as the food images were presented in both load conditions, it was not possible to test for perceptual load effects on memory (this design decision was taken in order to remove the need for between-subject counterbalancing that might reduce sensitivity to find individual differences). To test whether the effects of perceptual load on food-related cognition also extend to memory, Experiment 3 repeated the paradigm of Experiment 2 with the change that different images were presented under low and high perceptual load. This also afforded the opportunity to test whether the enhanced food-related memory linked to food disinhibition, hunger and BMI, as observed across both Experiments 1 and 2, would be found in both load conditions. In addition, to correct for the possibility that our failure to detect food-related attentional biases in prior experiments was due to our use of affectively matched non-food distractors (flowers and leaves), these were replaced with neutral office stimuli. This change in stimulus category also allowed us to generalise the food memory bias beyond the specific non-food stimulus set used in Experiments 1 and 2.

2.4.1. Method

Participants. One hundred female participants aged between 18-35 years ($M = 19.48$, $SD = .17$). All other details were the same as in Experiment 1 and 2. One participant was excluded from the analysis due to incomplete data.

Stimuli and procedure. The stimuli and procedure were identical to Experiment 2, with the following exceptions. To correct for the possibility that the non-food distractors were too pleasant as a control category, they were changed to office stimuli (e.g., stapler, files and calculator). Twelve office stimuli and an additional six food stimuli (combined with the original six food stimuli used in Experiments 1 and 2) were selected from the Foodpics database. Images were matched on the key visual features of brightness, contrast and familiarity (all $ps > .110$, see table S1 for means). Food images were rated as significantly more positive in valence and higher in arousal than office images, as we wanted to maximise the possibility of observing attentional bias.

In order to test for load effects on memory, different distractor sets were presented in low and high load blocks. For example, food distractors 1 – 6 and non-food distractors 7 – 12 were presented in low load blocks; food distractors 13 – 18 and non-food distractors 19 – 24 were presented in high load blocks. We ran a pilot study ($N = 12$) to obtain individual distractor costs for each stimulus and create sets that were equally distracting. In addition, distractor sets were counterbalanced between subjects so that each distractor image was equally represented in the high and low load conditions. Participants in the two counter-balancing groups did not differ in terms of disinhibition, hunger or BMI (all p 's $> .47$).

The extra distractor images were added to the memory test, no other changes to the stimuli were made.

For practical reasons we changed to online rather than in person data collection. Experiment 3 was run as an online experiment using Inquisit 5 (2016) software. Several changes to the task and procedure were made to adapt the experiment for online use. Firstly, as lighting and screen brightness could not be controlled for, the screen background was changed to grey and the letter stimuli changed to black. This was because the grey screen was less susceptible to glare and the black letter stimuli less affected by brightness.

Secondly, the size and locations were kept constant across different screens by using a calibration procedure. Participants were required to change the length of a line on the screen to match the length of a standard sized bank card. This was then used to calibrate the pixels to millimetre ratio on that screen and generate stimuli in the same sizes and locations as in Experiment 2.

Finally, to ensure participants had understood the instructions without the experimenter being present, they had to correctly answer an example trial to show their understanding. The number of practice trials was increased to 24 under both levels of load and they had to achieve 60% accuracy under both low and high load. Any participants who attempted the practice blocks more than 5 times were not allowed to complete the rest of the experiment.

2.4.2. Results

Reaction times. The effect of load on distraction by food stimuli was tested using an ANOVA as in Experiments 1 and 2. RTs (correct responses only) were entered into a 2 x 3 within subject ANOVA, with the factors of load (low, high) and distractor type (food, office, absent). Table 3 presents mean RTs, accuracy and distractor costs across different conditions.

Table 3

Mean RTs (SE in parentheses) and percentage accuracy rates across different distractor conditions under low and high load in Experiment 3.

	Distractor condition			Distractor costs	
	F	NF	ND	F-ND	NF-ND
Low load					
RT (ms)	532 (6)	534 (7)	501 (5)	31	33
% error	14	14	12		
High load					
RT (ms)	704 (14)	699 (12)	711 (13)	-7	-12
% error	28	30	25		

Note. F= food distractor, NF= non-food distractor, ND= no distractor, F-ND= food distractor cost, NF-ND = non-food distractor cost.

The main effects of load, distractor and the load x distractor interaction were replicated from the previous two experiments. The load x distractor type ANOVA showed a significant main effect of load, $F(1, 98) = 359.66, p < .001$. $N_p^2 = .79$. RTs were longer in the high load than in the low load conditions, again confirming that the load manipulation was effective in increasing the task difficulty. There was a significant main effect of

distractor type, $F(2, 98) = 5.28, p = .009, N_p^2 = .05$, with greenhouse geisser correction applied as Mauchly's test suggests sphericity was violated, $X^2(2) = 22.05, p < .001$. The interaction between load x distractor was also significant, $F(2, 98) = 17.76, p < .001, N_p^2 = .15$, greenhouse geisser correction applied as Mauchly's test suggests sphericity was violated for the interaction, $X^2(2) = 11.06, p = .004$.

Planned contrasts were conducted on distractor costs under low and high load, to investigate the significant interaction. Under low load there was a significant effect of distractor, $F(1,98) = 14.54, p < .001, N_p^2 = .13$, but not under high load, $F(1,98) = 1.69, p = .197, N_p^2 = .02$. This once again replicates the finding that distractor interference was eliminated by high load.

Follow up *t*-tests suggest that under low load RT's were significantly slowed when a food distractor was present, $t(98) = 9.06, p < .001, d = .54$, and when a non-food distractor was present, $t(98) = 7.44, p < .001, d = .55$. However, there was no significant difference on RT between food and non-food distractors, $t(98) = .35, p = .730, d = .03$. Hence, there is no evidence for attentional bias even after changing the non-food category to neutral office stimuli.

As our final experiment again found no evidence of attentional bias, we conducted Bayesian analyses in order to establish the extent to which the data provided evidence for the null hypotheses. We calculated Bayes factors for non-significant results important to our interpretation: the difference between food and non-food distraction under low load; and both food and non-food distraction under high load. Using the benchmarks provided by Dienes (2014) a Bayes factor of less than a third is evidence for the null hypothesis, more than three is evidence for the alternative hypothesis and any value in between reflects

insensitivity. A half normal distribution was used, as all predictions were directional. Bayesian analyses were conducted using the Dienes (2008) online Bayes calculator.

To calculate a Bayes factor (B) for the difference between food and non-food distractor RT under low load (our measure of food-related attentional bias), a prior of 10.5 was obtained from averaging previous research that found a significant food related RT bias across participants (Ahern, Field, Yokum, Bohon & Stice, 2010; Werthmann, Jansen & Roefs 2016; Kakoschke, Kemps & Tiggemann, 2015; Deluchi, Costa, Friedman, Goncalves & Bizarro, 2017). The resulting Bayes factors were: Experiment 1, $B = .43$; Experiment 2, $B = .25$; Experiment 3, $B = .38$. Therefore, in Experiments 1 and 3, the Bayes factors narrowly missed the .3 threshold for sensitivity. In Experiment 2, we obtained a sensitive Bayes factor, suggesting that food did not preferentially capture attention in this Experiment.

To calculate the Bayes factors for the non-significant effect of distraction by food and non-food stimuli under high load in Experiment 1, a prior of 60 was used from Forster & Lavie's (2008) previous research. As we obtained significant effects of distraction by food and non-food stimuli in Experiment 1, we were able to use these as priors for the Bayesian analyses in Experiment 2. It was preferable to use priors from Experiment 1 over previous perceptual load experiments as Experiment 1 specifically tested the research questions of interest in an almost identical design to Experiment 2, therefore, the priors were more informative. Furthermore, as the distractor effects were smaller than those from Forster & Lavie's study (2008), using these as priors gave a more conservative estimate of sensitivity. To calculate the Bayes factors for the non-significant effect of distraction by food and non-food stimuli under high load in Experiment 2, priors of 17 and 20

(respectively) were used from Experiment 1. Lastly, in Experiment 3, a prior of 31 was used for food, and a prior of 35 was used for non-food from Experiment 2.

Bayes factors for distraction by food and non-food under high load are reported in their respective order (i.e., food then non-food): Experiment 1, $B = .05$ and $B = .15$; Experiment 2, $B = .12$ and $B = .11$; Experiment 3, $B = .08$ and $B = .07$. Therefore, Bayesian analyses suggested a sensitive null effect of distraction from both food and non-food stimuli under high load across all three experiments.

Error rates. There was a significant main effect of load, $F(1,98) = 213.19$, $p < .001$, $N_p^2 = .69$, error rates were higher under high load than low load. There was also a significant main effect of distractor, $F(2,198) = 10.36$, $p < .001$, $N_p^2 = .10$, again this reflected slightly higher error rates on food and control distractor present trials compared to distractor absent, greenhouse geisser correction was used, $X^2(2) = 34.36$, $p < .001$. Finally, there was a non-significant interaction, $p > .3$.

Recognition accuracy for images. The mean percentage of food and non-food images recognised in each load condition are presented in Figure 4. To test the effect of load on memory for food and non-food images, recognition accuracy rates were entered into a within subjects 2 x 2 ANOVA, with the factors of load (low, high) and image type (food, office).

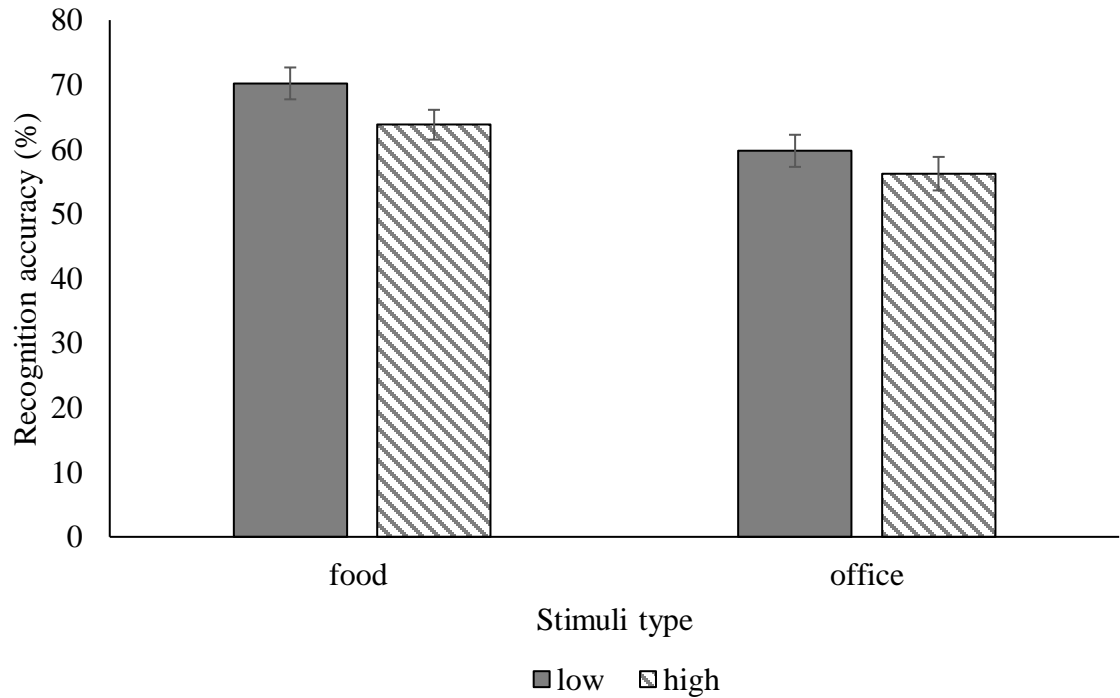


Figure 4. Mean recognition accuracy of food and office images presented under low and high perceptual load

The ANOVA revealed a main effect of load, $F(1,98) = 5.29$, $p = .024$, $N_p^2 = .05$. Recognition accuracy was higher for images presented under low load than high load. In addition, there was a highly significant main effect of distractor, $F(1,98) = 19.30$, $p < .001$, $N_p^2 = .17$. As in previous experiments, recognition accuracy was higher for food images than for non-food images. There was a non-significant load x memory stimulus interaction, $F(1,98) = .56$, $p = .455$, $N_p^2 = .01$, implying a similar food memory bias regardless of load. To confirm the presence of a food memory bias under both levels of load, follow up within subject *t*-tests were conducted comparing the difference in recognition accuracy between food and non-food images under low and then high load. The *t*-tests showed that participants recognised significantly more food images than non-food images under both low load, $t(98) = 3.57$, $p = .001$, $d = .42$, and high load, $t(98) = 2.84$, $p = .005$, $d = .31$.

Individual differences in food-related attention and memory. Correlations between food and non-food distractor costs and their corresponding memory recognition accuracy, split by load, are presented in Table 4. Like in Experiments 1 and 2, the correlations between attention and memory were not significant, meaning that increased distraction by food and non-food stimuli was not associated with better recognition accuracy for those images. Attention and memory biases for food were not associated under low load, as in Experiment 1 and 2. However, under high load, a positive correlation between attention and memory bias narrowly missed significance, $p = .054$. The extent to which load modulated distraction by food images was unrelated to the extent to which it modulated recognition accuracy of those food images, $r(98) = .11$, $p = .132$, 95% CIs [-.08, .30].

Table 4

One tailed Pearson R correlations and confidence intervals between attention and memory measures in Experiment 3.

	Distractor cost (ms)				Bias scores (food - non food)	
	Low load		High Load		Low load	High load
Recognition accuracy	Food	Office	Food	Office	attentional bias	attentional bias
Low load Food recognition accuracy	.03 [-.18, .25]	-	-	-	-	-
Low load Non-food recognition accuracy	-	0.16 [-.02, .32]	-	-	-	-
High load Food recognition accuracy	-	-	.02 [-.16, .19]	-	-	-
High load Non-Food recognition accuracy	-	-	-	.01 [-.18, .20]	-	-
Low load memory bias	-	-	-	-	.02 [-.16, .21]	-
High load memory bias	-	-	-	-	-	.16 [-.08, .38]

*correlation is significant at the .05 level ** correlation is significant at the .001 level

Note. Memory bias = number of food images recognised – number of non-food images recognised.

The role of individual differences. The full set of correlations between attention, memory and individual difference traits are presented in Table S4 and S5 of the Supplementary materials. As in both of our previous experiments, disinhibition positively predicted the number of food images recognised in the memory test—however, this relationship was confined to the high load condition, $r(97) = .18, p = .034$, 95% CIs [-0.01, .35]. There was no relationship between disinhibition and recognition accuracy under low load, $r(97) = .06, p = .268$, 95% CIs [-.15, .25]. Disinhibition was, as in previous experiments, not associated with the number of non-food images recognised under low, $r(97) = .05, p = .325$, 95% CIs [-.16, .25], or high load, $r(97) = .09, p = .183$, 95% CIs [-.11, .29]. Hunger again correlated with recognition accuracy of food images, both under low, $r(97) = .25, p = .006$, 95% CIs [.03, .46], and high load, $r(97) = .22, p = .016$, 95% CIs [.02, .42]. However, in contrast to previous experiments, hunger also predicted improved recognition accuracy of the non-food images under both low, $r(97) = .18, p = .021$, 95% CIs [-.01, .36], and high load, $r(97) = .20, p = .037$, 95% CIs [-.03, .42]. There was no relationship between BMI and recognition accuracy of food images presented under low load, $r(97) = .03, p = .379$, 95% CIs [-.24, .17], however, for food images presented under high load there was a trend in keeping with previous experiments, but this did not reach significance, $r(97) = .14, p = .087$, 95% CIs [-.03, .29]. There was no evidence of correlations between BMI and recognition accuracy of non-food images under low, $r(97) = .00, p = .482$, 95% CIs [-.16, .15], or high load, $r(97) = .02, p = .409$, 95% CIs [-.14, .18].

Our finding linking hunger to enhanced memory for food replicates two prior findings (Morris & Dolan, 2001; Talmi et al., 2013). We further examined whether hunger might play an underlying role in the observed new correlations between recognition accuracy and both disinhibition and BMI, which were observed in each of our three

experiments, with the exception of BMI and recognition accuracy in Experiment 3. This did not appear to be the case. Neither disinhibition nor BMI correlated with hunger in any of the three experiments, all $ps > .177$. Furthermore, correlations between disinhibition, BMI and recognition accuracy of food stimuli remained significant after controlling for hunger, across all experiments. Experiment 1: disinhibition, $r(55) = .23$, $p = .044$, 95% CIs [-.054, .499], and BMI, $r(55) = .31$, $p = .009$, 95% CIs [.126, .515]. Experiment 2: disinhibition, $r(100) = .18$, $p = .036$, 95% CIs [-.03, .38], and BMI, $r(100) = .25$, $p = .005$, 95% CIs [-.09, .41]. Experiment 3: disinhibition and recognition accuracy for food stimuli under high load only, $r(97) = .18$, $p = .036$, 95% CIs, [-.01, .36].

2.4.3. Discussion

Experiment 3 once again replicated our key finding that perceptual load eliminates distraction from both food and non-food stimuli alike. As in our previous experiments, but in contrast to prior evidence, food stimuli did not cause any distraction above and beyond non-food stimuli (i.e., attentional bias). Most importantly, Experiment 3 also demonstrated that the effects of perceptual load on food-related cognition extend to memory: Recognition accuracy for both food and non-food images was reduced under high perceptual load. To our knowledge this is the first experiment to simultaneously examine load effects on both distraction and recognition memory for the same stimuli. An intriguing feature of our results is that despite distractor interference being eliminated in the high load condition, participants were able to recognise the distractor images used in this condition with accuracy well above chance. This implies that processing of the images was attenuated rather than entirely eliminated in the high load condition (cf. Triesman, 1969). This attenuated processing appears to have been sufficient to allow above chance recognition of the distractor images, although as we did not include confidence ratings it is unclear whether this memory performance reflected explicit recognition as opposed to more implicit familiarity judgements. On the other hand, the attenuated processing was not of sufficient strength to cause distractor interference.

Finally, Experiment 3 replicated the previous experiments' finding of a memory bias, which was observed here in both load conditions, as well as the relationship of disinhibition and hunger to food recognition accuracy. As in Experiments 1 and 2, disinhibition was still correlated with food recognition accuracy even when controlling for hunger. Overall the pattern of results was very similar to previous experiments despite the

change to online testing—to our knowledge this is the first online replication of perceptual load effects on any form of distractor interference. The one way in which the online presentation appeared to reduce sensitivity was with respect to BMI, which was measured with a stadiometer with an integrated height measure in previous experiments but based on self-report here; this change appears likely to explain the reduction in the strength of the correlation between BMI and food recognition accuracy.

2.5. General Discussion

Across our three highly powered experiments, our findings establish for the first time that two key aspects of cognitive processing of food stimuli—attention and memory—can be powerfully modulated by perceptual load. The ability of food images to cause distractor interference was consistently eliminated under high load, and recognition accuracy for food images was also reduced in the high load condition. Indeed, our results imply that food stimuli are subject to perceptual load modulation to the same degree as non-food stimuli: each of our experiments revealed a similar magnitude of load effects for food versus non-food.

Prior research has demonstrated that although perceptual load modulates the overwhelming majority of stimuli, a small number of ‘special’ stimulus categories, such as faces, have been highlighted as having immunity to perceptual load effects (e.g., Murphy, Groeger & Greene, 2016, for review). Interestingly, one prior study, by Gupta and colleagues (2016), found that several classes of rewarding stimuli (erotic photographs, happy faces and stimuli that had been experimentally associated with financial reward) were unaffected by perceptual load. Our research clarifies that, despite their association with reward, food cues do not hold any special attentional status with respect to perceptual load modulation.

Our findings hence support our proposal that Load Theory can be usefully applied as a framework from which to understand the role of attention and memory in eating behaviours, accommodating prior findings with respect to both cognitive bias research and inattentive eating. To recap, under low perceptual load attentional capacity is available to

process irrelevant stimuli, with the result that irrelevant food cues may attract attention, potentially triggering food cravings (and, ultimately, consumption). However, under high perceptual load attentional capacity is fully exhausted by the task, meaning that irrelevant food cues cannot attract attention.

Our results demonstrate that high perceptual load not only reduces attentional capture by food cues during the task, but also reduces subsequent memory for these food cues. While the direct link between food memory bias and consumption has not yet been tested, the pathway between attention to food cues and later consumption necessarily depends on memory processes (May et al., 2012; Werthmann et al., 2014). As such, our findings suggest that engaging in high perceptual load tasks could not only reduce temptation from external food cues during the task but may also reduce cravings associated with these cues even after the task is completed.

One useful direction for future research would be to directly test the effect of perceptual load on cravings. In keeping with our proposed application of Load Theory, prior research has demonstrated that cravings can be reduced by real world tasks which are high in perceptual load. For example, the visually demanding game Tetris has been shown to reduce craving for food (Skorka-Brown, Andrade, & May, 2014). However, as these prior studies compare to a no task baseline, rather than using a controlled manipulation of perceptual load, it remains to be clarified whether these prior demonstrations can be attributed to perceptual load effects as opposed to other task demands (e.g., motor demands).

We have highlighted above some potentially beneficial effects of perceptual load in preventing external food cues from producing unwanted cravings. On the other hand, our suggested application of Load Theory predicts that high perceptual load tasks may have a negative (in contexts where increased consumption is undesirable to the individual) impact once eating commences. In this context, perceptual load would theoretically reduce processing of the food being consumed, with the potential consequences of reducing awareness of important satiety signals and disrupting memory of intake.

Such effects would depend on the perceptual load effects established here applying not only to visual food cues, as in the present study, but to olfactory and gustatory food cues and interoceptive satiety cues. Two sources of existing evidence support this possibility. First, the effects of perceptual load (typically operationalised as visual load) have already been established to extend cross-modally to the auditory, olfactory and tactile domains (Dalton, Lavie & Spence, 2009; Forster & Spence, 2018; Macdonald & Lavie, 2011), as well as to internally generated stimuli (task-unrelated thoughts, Forster & Lavie, 2009). Second, prior demonstrations of inattentive eating effects (in terms of both immediate effects and subsequent memory-mediated effects on intake) have tended to use tasks that are high in perceptual load, such as television or computer games (Higgs, 2015; Robinson et al., 2013). An important next step in applying Load Theory to food-related cognition would be to integrate controlled manipulations of perceptual load, as used in the present study, into investigations of inattentive eating and memory. Such work is currently being conducted in our lab.

Our proposed application of Load Theory to food-related cognition has focused on the role of perceptual load. However, Load Theory also discusses another type of load: load

on cognitive control processes such as working memory (WM). Contrary to the effect of perceptual load, high WM load in a task is argued to increase vulnerability to distraction by taxing the executive resources necessary for efficient distractor rejection (Lavie, 2005; 2010). In contrast to the effect of perceptual load, high working memory load should therefore increase unwanted distraction by irrelevant food stimuli. This carries the real world implication that while perceptual load may help people to avoid attention to tempting food cues, high levels of WM load might be especially problematic for people attempting to ignore food (i.e., if they are on a diet) and may counterproductively increase the risk of noticing the food stimulus.

An exciting recent line of research by van Dillen and colleagues might initially seem to conflict with these latter predictions of Load Theory. Van Dillen, Papies & Hofmann (2013), found reduced rather than increased attentional bias to food under high WM load. More recently, Van Dillen and Van Steenbergen demonstrated a reduced neural response to food images under high, versus low, WM load. These results are compelling in suggesting that higher level processes also play a key role in processing the rewarding value of food stimuli, yet might initially seem at odds with the predictions of Load Theory regarding WM load. However, it is important to note that neither of these studies presented food cues as irrelevant distractors. Rather, the food cues appeared as targets requiring some task response, meaning that not only was it necessary to attend to the food cues in order to perform the task (e.g., to identify their location or classify them as edible or non-edible), but doing so quickly would in fact benefit, rather than disrupt, performance. As there was no reason for participants to recruit executive resources to suppress attention to the food, this study does not directly test the predications of Load Theory regarding WM load, and

differs somewhat from real world situations in which people may wish to ignore entirely irrelevant food cues as they go about their daily tasks. Establishing the effects of WM load on the ability to ignore entirely irrelevant food cues is hence an important direction for future research. In particular, clarifying whether WM load may in some cases increase attention to food will enable more accurate recommendations regarding task-based management of eating behaviour.

Moving away from Load Theory, an unexpected yet striking result of our study was the lack of any clear evidence for biased attention towards food versus non-food stimuli, either across participants or in relation to any of a range of traits previously implicated in food-related cognition. In all three experiments food images captured attention to the same extent as non-food images despite being high-fat, high-sugar, rated highly on VAS measures of palatability and craving in the FoodPics database (Blechert et al., 2014). Attentional bias was not observed even in Experiment 3 where we used office-based control stimuli pre-rated to be less positive and lower in arousal than the food stimuli. This finding conflicts with some previous studies that have found attentional bias for food (Werthmann, Jansen & Roefs, 2015), including one study using a similar task and food stimuli from the same database (Cunningham and Egeth, 2018). On the other hand, as noted in our introduction, there is inconsistency in the existing evidence for attentional bias in regard to individual differences. In addition, several reviews have highlighted contradictory study evidence for the presence of a general attentional bias (for reviews see Doolan et al., 2015; Nijs & Franken, 2012; and Werthmann et al., 2015). Taking these prior inconsistencies together with the complete absence of any bias effects across our three experiments, we speculate that attentional bias for food cues may be either less robust than

sometimes assumed, or dependent upon some hidden moderator. Understanding of attentional bias, and in particular trait differences in food-related cognition, would benefit from future research including more internal replication and pre-registered replication of existing findings.

The lack of attentional bias is all the more striking in the light of our finding of a consistent and robust memory bias for food, across all three experiments. In contrast to previous memory bias studies (Morris & Dolan, 2001; Soetens et al., 2014; Talmi et al, 2013), a general memory bias for food was found across individuals, with participants recognising on average approximately 20% more food versus non-food images across experiments. Across all three experiments recognition accuracy for food was also consistently enhanced among individuals reporting high levels of hunger, as well as those high in trait tendency towards uncontrolled eating (disinhibition). Objectively measured BMI also significantly predicted food recognition accuracy in both Experiments 1 and 2 (with Experiment 3, which used the less reliable self-report measure of BMI, showing a similar trend).

The relation of hunger to food recognition accuracy replicates the prior findings of Morris and Dolan (2001) and Talmi and colleagues (2013). Interestingly, our novel findings of enhanced memory in individuals high in disinhibition and BMI were not simply driven by hunger: hunger was unrelated to disinhibition and BMI in all three experiments, and all correlations between disinhibition, BMI and recognition accuracy of food images were maintained even when controlling for hunger. In other words, individuals with a high BMI or a tendency towards uncontrolled eating had improved memory for food regardless of their level of hunger. A promising direction for future research would be to clarify whether

these intriguing individual differences relationships reflect a role of memory in conferring vulnerability to overeating, or conversely might reflect an effect of habitual over-eating on memory (e.g., perhaps driven by enhanced familiarity or reward associations for the food stimuli).

Another key question for further research is at what stage the enhanced processing underlying the food memory bias occurred. For example, it could be that food stimuli receive enhanced processing during encoding, that food-related memories are more easily consolidated, or that food-related memories are more accessible to be retrieved. For now we note one clue: the fact that the bias itself (i.e., the difference between food versus non-food recognition accuracy, rather than recognition accuracy per se) did not appear to be modulated by perceptual load, along with the lack of correlation between any attention and memory biases, is clearly inconsistent with any view of memory biases as being simply a consequence of increased attention to the food cues. Rather, these biases appear to reflect an aspect of memory independent of attention.

Returning to our key aim of applying Load Theory to food-related cognition, it is important to note that regardless whether a bias was observed (as in the case of memory) or not (as in the case of attention), perceptual load nevertheless modulated cognitive processing of food and non-food stimuli alike. Hence, the lack of attentional bias in our dataset does not undermine our key conclusions regarding the ability of perceptual load to modulate attention to food cues. Nevertheless, it should be noted that the magnitude of the food memory bias itself (i.e., difference in accuracy for food versus non-food) was not altered by load. Given this, it remains unclear how a food attentional bias, where observed, would be influenced by load. In cases where attentional effects are fully eliminated as in the

present study, floor effects make any attentional bias appear unlikely. On the other hand, in cases where food-related attentional effects were reduced rather than eliminated, biased attention to food-versus non-food might still be observed, following the pattern seen in the memory biases. Future research should clarify this issue. For now, we conclude that, critically, the impact of any such attentional biases would be substantially mitigated by the general load-related reduction in attention to food (as well as non-food) stimuli. In other words, a chocolate bar stuffed vending machine is far less likely to catch our eye, potentially leading to temptation, in situations of high versus low load.

To summarise, across our three experiments we demonstrate that perceptual load modulates both attention (Experiments 1-3) and memory (Experiment 3) of food cues. In real world terms, our findings imply that vulnerability to the multitude of food cues in our obesogenic environment (e.g., posters and billboards) would be greatest when attention is engaged in a perceptually simple task. More broadly, our findings provide initial support for the use of Load Theory as a framework for understanding food-related cognition. The unexpected lack of evidence for attentional bias and consistent individual differences questions the generalisability of these biases. Our research also highlights the overlooked area of memory biases for food, which may prove to be an interesting avenue for further study, particularly the bidirectional relationship between attention and memory and the influence of individual differences.

2.6. Supplementary information

Table S1

Mean and standard error for food, nature and office stimuli ratings (retrieved from the Foodpics database, Blechert et al., 2014).

	Familiarity	Valence	Arousal	Complexity	Brightness	Contrast
Food	98.28 (.51)	56.09 (2.15)	39.00 (2.29)	36.24 (3.24)	45.16 (9.01)	59.53 (2.35)
Nature	89.17 (5.44)	60.27 (3.46)	36.08 (3.06)	43.73 (3.69)	38.32 (4.10)	53.41 (5.08)
Office	98.66 (.60)	44.14 (1.32)	17.66 (1.73)	24.81 (3.61)	38.07 (6.97)	53.14 (6.29)

Table S2

One tailed Pearson R correlations and 95% bootstrapped confidence intervals between questionnaire measures of individual differences, distractor costs and recognition accuracy in Experiment 1.

	Distractor cost (ms)				Recognition accuracy		Bias scores (food – non-food)			Load modulation of distractor cost (low load – high load)	
	Low load		High Load		-	-	Low load	High load			
	Food	Non food	Food	Non food	Food	Non food	attentional bias	attentional bias	Memory bias	Food	Non food
TFEQ_D	.03 [-.23, .33]	-.01 [-.28, .25]	-.21 [-.44, .06]	.27* [-.01, .49]	.25* [-.08, .52]	-.01 [-.24, .24]	.03 [-.23, .30]	-.35** [-.55, -.13]	.16 [-.15, .47]	.18 [-.13, .42]	-.24* [-.46, .05]
TFEQ_R	.29* [-.02, .51]	.16 [-.13, .43]	.01 [-.25, .25]	-.11 [-.38, .17]	-.04 [-.32, .25]	.04 [-.26, .33]	.15 [-.16, .40]	.09 [-.20, .37]	-.05 [-.34, .26]	.18 [-.09, .45]	.17 [-.08, .41]
BIS 11	-.15	-.21	-.09	.10	-.05	-.04	.01	-.13	0	-.03	-.19
Total	[-.41, .14]	[-.43, .04]	[-.37, .18]	[-.14, .36]	[-.32, .22]	[-.30, .23]	[-.29, .39]	[-.37, .10]	[-.23, .23]	[-.28, .24]	[-.38, .04]
BIS	-.14	-.13	-.13	.09	.01	-.24*	-.03	-.15	.19	.01	-.14
attention	[-.36, .15]	[-.32, .07]	[-.40, .13]	[-.12, .31]	[-.21, .22]	[-.46, .05]	[-.27, .29]	[-.39, .07]	[-.08, .42]	[-.26, .27]	[-.36, .06]

BIS	-.02	-.18	-.12	-.02	-.05	.05	.10	-.06	-.07	.07	-.07
motor	[-.33, .34]	[-.43, .09]	[-.36, .09]	[-.28, .27]	[-.29, .18]	[-.27, .38]	[-.25, .48]	[-.30, .19]	[-.33, .20]	[-.17, .33]	[-.31, .19]
S Reward	-.07	-.17	-.13	-.04	-.00	.06	.05	-.05	-.04	.05	-.05
	[-.45, .35]	[-.38, .05]	[-.44, .25]	[-.29, .21]	[-.31, .30]	[-.20, .31]	[-.29, .40]	[-.35, .25]	[-.35, .26]	[-.39, .39]	[-.28, .20]
DEBQ_E	.15	-.17	-.04	.09	-.03	-.08	.24*	-.09	.04	.12	-.16
	[-.10, .37]	[-.43, .09]	[-.32, .27]	[-.14, .30]	[-.26, .19]	[-.31, .19]	[-.04, .53]	[-.32, .13]	[-.18, .26]	[-.17, .38]	[-.39, .07]
BMI	.21	.17	.03	.11	.33**	0.12	.07	-.07	.12	.11	-.02
	[-.11, .53]	[-.14, .49]	[-.24, .33]	[-.18, .35]	[-.15, .53]	[-.12, .31]	[-.23, .36]	[-.29, .18]	[-.11, .37]	[-.13, .35]	[-.26, .30]
VAS	.09	.01	.19	.04	.21	-.15	.08	.09	.25*	-.08	-.04
Hunger	[-.15, .34]	[-.25, .27]	[-.05, .04]	[-.21, .30]	[-.09, .48]	[-.46, .18]	[-.16, .32]	[-.16, .34]	[-.06, .52]	[-.29, .14]	[-.28, .22]

*correlation is significant at the .05 level ** correlation is significant at the .001 level

Note: TFEQ_D = Three factor eating questionnaire, disinhibition subscale; TFEQ_R = Three factor eating questionnaire, restraint subscale; BIS 11 Total = Baratt Impulsivity Questionnaire, total score; BIS attention = Baratt Impulsivity Questionnaire, attentional subscale; BIS motor = Baratt Impulsivity Questionnaire, motor subscale; S Reward = Sensitivity to punishment and reward Questionnaire, reward subscale; DEBQ_E = Dutch Eating Behaviour Questionnaire, external eating subscale; BMI = Body Mass Index; VAS Hunger = self-reported hunger using visual analogue scale.

Table S3

One tailed Pearson R correlations and 95% bootstrapped confidence intervals between questionnaire measures of individual differences, distractor costs and recognition accuracy in Experiment 2.

	Distractor cost (ms)				Recognition accuracy		Bias scores (food – non-food)			Load effect on reaction time	
	Low load		High Load		-	-	Low load	High load			
	Food	Non food	Food	Non food	Food	Non food	attentional bias	attentional bias	Memory bias	Food	Non food
TFEQ_D	.01	-.22*	.19*	.19*	.18*	.09	.20*	-.03	.06	.17*	-.27**
	[-.16, .16]	[-.37, -.05]	[-.02, .39]	[.02, .37]	[-.02, .35]	[-.07, .25]	[.02, .36]	[-.22, .16]	[-.22, .16]	[-.37, .03]	[-.45, -.09]
TFEQ_R	.01	-.11	-.04	-.03	.02	.07	.10	-.01	-.04	.04	-.03
	[-.22, .25]	[-.28, .08]	[-.22, .14]	[-.20, .14]	[-.17, .22]	[-.15, .28]	[-.13, .32]	[-.14, .15]	[-.22, .15]	[-.14, .22]	[-.18, .13]
BIS 11	-.08	-.03	-.06	-.08	.11	-.15	-.05	.03	.22*	.00	.05
Total	[-.28, .12]	[-.22, .15]	[-.26, .14]	[-.29, .12]	[-.11, .33]	[-.34, .07]	[-.25, .15]	[-.17, .23]	[.03, .39]	[-.17, .18]	[-.13, .24]
BIS	-.14	-.03	.01	.03	.23**	-.16	-.11	-.02	.33**	-.10	-.04
attention	[-.32, .05]	[-.20, .15]	[-.18, .20]	[-.16, .24]	[.01, .43]	[-.34, .03]	[-.32, .11]	[-.23, .17]	[.16, .47]	[-.27, .07]	[-.23, .14]

BIS	-.02	-.01	.03	.00	.17*	-.02	-.01	.03	.15	-.04	.00
motor	[-.22, .18]	[-.19, .17]	[-.17, .20]	[-.19, .17]	[-.07, .40]	[-.23, .19]	[-.19, .18]	[-.14, .20]	[-.06, .34]	[-.20, .14]	[-.13, .15]
S Reward	.04	-.09	-.10	.00	.04	.13	.12	-.07	-.08	.12	-.04
	[-.18, .26]	[-.29, .14]	[-.32, .11]	[-.20, .20]	[-.13, .20]	[-.04, .27]	[-.06, .30]	[-.27, .13]	[-.27, .13]	[-.11, .32]	[-.28, .18]
DEBQ_E	-.10	-.04	.08	.20*	.09	-.04	-.06	-.12	.10	-.13	-.19*
	[-.32, .11]	[-.24, .16]	[-.13, .26]	[.01, .37]	[-.17, .34]	[-.26, .18]	[-.24, .13]	[-.24, .00]	[-.09, .29]	[-.31, .06]	[-.36, -.02]
BMI	.08	.10	.11	.21*	.24**	.10	-.01	-.10	.11	-.05	-.13
	[-.06, .21]	[-.10, .27]	[-.07, .29]	[.07, .34]	[.06, .41]	[-.09, .26]	[-.20, .17]	[-.26, .07]	[-.10, .30]	[-.22, .10]	[-.26, .00]
VAS	.03	-.13	.08	.14	.20*	.05	.14	-.07	.11	-.05	-.19*
Hunger	[-.15, .23]	[-.32, .08]	[-.11, .24]	[-.04, .32]	[-.01, .40]	[-.15, .23]	[-.05, .34]	[-.25, .11]	[-.08, .30]	[-.23, .13]	[-.35, .00]

*correlation is significant at the .05 level ** correlation is significant at the .001 level

Note: TFEQ_D = Three factor eating questionnaire, disinhibition subscale; TFEQ_R = Three factor eating questionnaire, restraint subscale; BIS 11 Total = Baratt Impulsivity Questionnaire, total score; BIS attention = Baratt Impulsivity Questionnaire, attentional subscale; BIS motor = Baratt Impulsivity Questionnaire, motor subscale; S Reward = Sensitivity to punishment and reward Questionnaire, reward subscale; DEBQ_E = Dutch Eating Behaviour Questionnaire, external eating subscale; BMI = Body Mass Index; VAS Hunger = self-reported hunger using visual analogue scale.

Table S4

One tailed Pearson R correlations and 95% bootstrapped confidence intervals between questionnaire measures of individual differences, distractor costs, bias scores, and load effects in Experiment 3.

	Distractor cost (ms)				Bias scores (food – non-food)			
	Low load		High load		Low load attention bias	High load attention bias	Load effect on reaction time	
	Food	Office	Food	Office			Food	Non-food
TFEQ_D	-.05 [-.23, .13]	.20* [.01, .35]	-.01 [.01, .35]	.01 [.01, .35]	-.20* [.01, .35]	-.02 [.01, .35]	-.02 [-.22, .18]	.10 [-.14, .31]
TFEQ_R	.12 [-.02, .27]	-.02 [-.20, .17]	.28** [.10, .46]	-.06 [-.29, .17]	.10 [-.11, .27]	.26** [.02, .48]	-.17* [-.32, -.01]	.04 [-.13, .22]
BIS 11 Total	-.14 [-.33, .05]	-.15 [-.31, .04]	.01 [-.15, .17]	-.06 [-.26, .15]	.04 [-.13, .20]	.05 [-.13, .23]	-.08 [-.21, .05]	-.04 [-.23, .17]
BIS attention	-.03 [-.22, .16]	-.02 [-.21, .18]	.11 [-.10, .30]	-.06 [-.26, .16]	-.01 [-.18, .16]	.13 [-.07, .31]	-.10 [-.29, .08]	.04 [-.18, .25]

BIS motor	-.14 [-.35, .06]	-.19* [-.35, .00]	-.02 [-.19, .16]	-.05 [-.23, .14]	.07 [-.10, .23]	.03 [-.14, .18]	-.05 [-.22, .12]	-.06 [-.24, .12]
S Reward	-.06 [-.26, .13]	-.14 [-.35, .07]	.01 [-.21, .19]	.01 [-.17, .18]	.08 [-.12, .28]	.00 [-.17, .16]	-.03 [-.23, .16]	-.09 [-.26, .11]
DEBQ_E	-.18* [-.36, .03]	.02 [-.18, .21]	-.04 [-.21, .14]	-.15 [-.32, .03]	-.13 [-.34, .13]	.10 [-.08, .26]	-.06 [-.23, .15]	.13 [-.10, .33]
BMI	-.03 [-.19, .12]	.28** [.02, .50]	.00 [-.16, .14]	.00 [-.19, .22]	-.25** [-.53, .01]	.00 [-.24, .20]	-.01 [-.17, .19]	.16 [-.11, .39]
VAS Hunger	.06 [-.18, .27]	-.03 [-.24, .19]	-.22* [-.40, -.05]	-.11 [-.28, .05]	.06 [-.16, .25]	-.08 [-.25, .12]	.21* [.03, .37]	.07 [-.11, .26]

*correlation is significant at the .05 level ** correlation is significant at the .001 level

Note: TFEQ_D = Three factor eating questionnaire, disinhibition subscale; TFEQ_R = Three factor eating questionnaire, restraint subscale; BIS 11 Total = Baratt Impulsivity Questionnaire, total score; BIS attention = Baratt Impulsivity Questionnaire, attentional subscale; BIS motor = Baratt Impulsivity Questionnaire, motor subscale; S Reward = Sensitivity to punishment and reward Questionnaire, reward subscale; DEBQ_E = Dutch Eating Behaviour Questionnaire, external eating subscale; BMI = Body Mass Index; VAS Hunger = self-reported hunger using visual analogue scale.

Table S5

One tailed Pearson R correlations and 95% bootstrapped confidence intervals between questionnaire measures of individual differences, recognition accuracy, bias scores, and load effects in Experiment 3.

	Recognition accuracy				Bias scores (food – non-food)			
	Low load		High load		Low load memory bias	High load memory bias	Load effect on recognition accuracy	
	Food	Office	Food	Office			Food	Non-food
TFEQ_D	.06 [-.15, .25]	.05 [-.16, .25]	.18* [-.01, .35]	.09 [-.11, .29]	.01 [-.17, .20]	.07 [-.14, .28]	-.10 [-.27, .09]	-.04 [-.23, .15]
TFEQ_R	.03 [-.14, .19]	.04 [-.16, .23]	.15 [-.03, .33]	.09 [-.09, .26]	-.01 [-.20, .17]	.05 [-.18, .27]	-.11 [-.30, .10]	-.04 [-.26, .15]
BIS 11 Total	-.08 [-.27, .09]	-.18* [-.35, .01]	-.07 [-.26, .12]	-.09 [-.25, .08]	.09 [-.09, .25]	.03 [-.18, .24]	-.02 [-.21, .18]	-.07 [-.24, .11]
BIS attention	-.16 [-.32, .01]	-.09 [-.29, .11]	-.12 [-.32, .07]	-.08 [-.25, .09]	-.06 [-.26, .14]	-.02 [-.22, .18]	-.04 [-.24, .15]	.00 [-.20, .19]

BIS motor	-.08 [-.28, .11]	-.16 [-.34, .03]	-.10 [-.27, .07]	-.07 [-.25, .14]	.07 [-.13, .25]	-.02 [-.23, .18]	.01 [-.16, .20]	-.07 [-.25, .12]
S Reward	-.05 [-.24, .16]	-.09 [-.27, .10]	-.02 [-.20, .15]	-.23* [-.43, -.04]	.03 [-.14, .20]	.20* [.01, .39]	-.02 [-.19, .15]	.12 [-.08, .33]
DEBQ_E	.05 [-.16, .27]	.02 [-.15, .19]	.31** [.12, .46]	.09 [-.15, .30]	.03 [-.16, .22]	.18* [-.04, .38]	-.22* [-.39, -.04]	-.05 [-.25, .13]
BMI	-.03 [-.24, .17]	.00 [-.16, .15]	.14 [-.03, .29]	.02 [-.14, .18]	-.03 [-.19, .11]	.10 [-.10, .27]	-.15 [-.29, .01]	-.02 [-.20, .17]
VAS Hunger	.25** [.03, .46]	.18* [-.01, .36]	.22* [.02, .42]	.20* [-.03, .42]	.06 [-.14, .28]	-.01 [-.21, .20]	.05 [-.16, .24]	-.03 [-.23, .18]

*correlation is significant at the .05 level ** correlation is significant at the .001 level

Note: TFEQ_D = Three factor eating questionnaire, disinhibition subscale; TFEQ_R = Three factor eating questionnaire, restraint subscale; BIS 11 Total = Baratt Impulsivity Questionnaire, total score; BIS attention = Baratt Impulsivity Questionnaire, attentional subscale; BIS motor = Baratt Impulsivity Questionnaire, motor subscale; S Reward = Sensitivity to punishment and reward Questionnaire, reward subscale; DEBQ_E = Dutch Eating Behaviour Questionnaire, external eating subscale; BMI = Body Mass Index; VAS Hunger = self-reported hunger using visual analogue scale.

2.7. Interim summary

This thesis proposed to apply perceptual load theory of attention to the eating behaviour literature. Paper one provided the first successful test of this potential framework, establishing that when using a robust manipulation of perceptual load (i.e., the visual search task), food stimuli were modulated by perceptual load in the same manner as non-food stimuli. This was a vital aspect of the proposed framework to establish, as if food stimuli had been ‘immune’ to the effect of perceptual load (like other categories of reward-associated stimuli, Gupta, Hur & Lavie, 2016), this would have raised the possibility that perceptual load theory was not a valid framework from which to make predictions about food-related cognitive processing. In addition, failure to reduce processing of simple visual food stimuli may have implied that other aspects of eating behaviour involving more complex multisensory stimuli (e.g., flavour) would similarly be immune to the effect of perceptual load.

External and internal food-related cues have been argued to contribute towards food craving and potential overconsumption in a mutually excitatory manner, whereby an increase of craving (of which intrusive thoughts are a central element) results in an increase in the attention-grabbing ability of the food cues, which in turn increases attentional bias to the food cues, which then strengthens the experience of the craving (Field & Cox, 2008). Therefore, due to the powerful effect of perceptual load on reducing distractor interference and memory for external food stimuli, a logical next step was to apply perceptual load theory to the reduction of internal food stimuli. In paper two we used an adaption of the visual search task (Forster & Lavie, 2009) to test whether perceptual load similarly reduced appetitive-related thoughts.

3. Paper two: A high perceptual load task reduces thoughts about chocolate, even while hungry.

Jenny Morris, Man Yung Keith Ngai, Martin R. Yeomans and Sophie Forster

Abstract

Intrusive thoughts about food can trigger cravings and result in unhealthy eating behaviour. Here we tested whether Load Theory of attention can be applied to the eating behaviour literature and reduce intrusive appetitive-related thoughts. Load Theory predicts that high levels of perceptual load in a task exhaust attentional capacity and so reduces interference from a range of stimuli, including intrusive thoughts. Therefore, this study aimed to test whether perceptual load reduced appetitive-related intrusive thoughts about chocolate. Sixty female participants were first given a chocolate bar to interact with for two minutes, before rating their levels of hunger, craving and liking for chocolate. They were then asked to avoid thinking about chocolate and instead focus attention on a visual search task. Perceptual load was manipulated within-subjects by varying the search set size. Appetitive-related thoughts were measured using both self-caught and probe-caught measures, allowing us to index load effects at varying levels of meta-awareness. Across subjects, the level of appetitive-related thoughts seen in the high load condition was significantly reduced, to less than half the level seen in the low load condition, on both probe and self-caught measures. Furthermore, self-reported hunger, craving and liking for the chocolate were positively correlated with appetitive-related thoughts under low load, but high perceptual load eliminated these state individual differences. Therefore, engaging in perceptually demanding tasks may be a worthwhile strategy for those wanting to disrupt the cycle of craving at the earliest stage.

3.1. Introduction

Overeating can result in obesity, a costly public health issue causing both physical and psychological harm to the individual. Craving has been argued to play a key role in eating behaviour, often resulting in over-eating (Hetherington & Macdiarmid, 1995), difficulty controlling weight (Meule, Westenhöfer & Kübler, 2011) and triggering binge eating episodes (Waters, Hill, & Waller, 2001). In addition, high levels of craving have been linked to higher BMI (Delahanty, Meigs, Hayden, Williamson, & Nathan, 2002; Rodin, Manuso, Granger, & Nelbach, 1991). Addiction models of craving have argued that cognitive processes, such as attentional bias (enhanced attentional processing of external stimuli) and subjective experience (e.g., substance-related thoughts), contribute towards substance-seeking behaviour (Franken, 2003; Field, Munafò & Franken, 2003). In relation to food, spontaneous intrusive thoughts have been argued to be a crucial trigger in a craving episode (May, Andrade, Kavanagh, & Hetherington, 2012). Research reviewed by Higgs (2016) suggests that when the initial thought is maintained in working memory, it then increases the salience of internal information (e.g., physiological state and episodic memories) and external information (e.g., food cues in the environment). For example, a person sitting at their desk may spontaneously think about chocolate, which makes them aware of how hungry they are and then increases the likelihood they notice the chocolate bar in their drawer. The latter example relates to attentional bias, which has been suggested to further perpetuate craving and increase the likelihood of consumption (Franken, 2003; Field, Werthmann, Franken, Hofmann, Hogarth & Roefs, 2016). Therefore, the intrusive thought will then continue to cause craving either until it has been satisfied (by consuming the chocolate) or until the cycle is broken. Following the presented logic, we reasoned that

one way of breaking the cycle would be by preventing the occurrence of appetitive-related intrusive thoughts.

The current research sought to elucidate the mechanisms underlying the most effective interventions to reduce appetitive-related thoughts, by applying a key theory of selective attention. Load Theory suggests that attention is a limited capacity resource, and that the extent to which task-irrelevant stimuli are selected for further processing depends on the level of perceptual load involved in the current task (Lavie, 2005; 2010). When perceptual demands are low (i.e. there is little information to process, or a very simple perceptual discrimination), this leaves spare capacity which can spill over to allow processing of other, task-irrelevant stimuli (Lavie, Hirst, De Fockert & Viding, 2004). In contrast, when perceptual demands are high (i.e., involving a large amount of information or complex and subtle perceptual discriminations), irrelevant stimuli are filtered out at an early stage and only relevant stimuli are passed on for further processing.

The powerful effects of perceptual load in reducing task-irrelevant processing have been demonstrated with a range of behavioural measures of distractor interference (e.g., Forster & Lavie, 2008) and intentional blindness (e.g., Cartwright-Finch & Lavie, 2006), as well as measures of neural processing (see Lavie, 2005 for review). The majority of research has focused on the visual domain, but perceptual load has also been shown to reduce processing of multisensory stimuli including olfactory (Forster & Spence, 2018), auditory (Macdonald & Lavie, 2011) and tactile (Dalton, Lavie & Spence, 2009). While most research has focused on the role of perceptual load in external tasks, recent research has shown that high perceptual load in mental imagery can have similar effects (Konstantinou & Lavie, 2013; Konstantinou, Beal, King & Lavie, 2014).

Critically, perceptual load has also been shown to reduce internally-generated sources of task-irrelevant processing: Using a thought-probing method, Forster & Lavie (2009) demonstrated that perceptual load reduced the frequency of task-unrelated thoughts (i.e. mind wandering). Perceptual load has also been shown to reduce task-unrelated thoughts in an applied driving setting, using naturalistic manipulations of perceptual load (Geden, Staicu, Feng, 2018). The effect of perceptual load has not been demonstrated, however, with highly salient thoughts such as food. However, perceptual load has been shown to reduce external distraction from both highly salient (Forster & Lavie, 2008) and food images (Morris, Yeomans & Forster, 2020) in an external distraction task. Therefore, we reasoned that perceptual load might have a similar effect on internal distraction in relation to food and have potential usage as a thought-reduction task.

Although intrusive thoughts have been proposed to be key in craving cycle, only one study that we are aware of has directly tested whether intrusive appetitive-related thoughts can be reduced. May, Andrade, Batey, Berry & Kavanagh (2010) tested the effects of visual imagery on appetitive-related intrusive thoughts. Participants either produced self-generated visual imagery about an activity of their choice or followed a guided visual imagery exercise during the subsequent ten-minute period. They responded to intermittent ‘thought probes’ during the experimental period. Fewer appetitive-related intrusive thoughts were reported during both the imagery conditions compared to a control condition. Their findings supported the idea that visual imagery can disrupt the earliest stage of the craving cycle. As visual imagery is known to load perceptual capacity in a similar manner to external perceptual load (Konstantinou & Lavie, 2013; Konstantinou, Beal, King &

Lavie, 2014), these prior results appear potentially consistent with our proposals regarding the ability of perceptual load to reduce intrusive thoughts.

Other studies have not directly measured intrusive thoughts during a task but have instead focused on post-task cravings. A variety of external tasks have been found to reduce cravings (Andrade, Pears, May & Kavanagh, 2012; Kemps, Tiggemann, Woods & Soekov, 2004; Kemps, Tiggemann & Hart, 2005; Steel, Kemps & Tiggemann, 2006; Kemps & Tiggemann, 2013; McClelland, Kemps & Tiggemann, 2006; Skorka-Brown, Andrade & May, 2014; Van Dillen & Andrade, 2016). Interestingly, some of these studies have used external tasks, such as Tetris (a visually demanding computer game), which are also likely to have been high in perceptual demand. However, generally these studies have compared a task to a no-task baseline, rather than systematically varying demand within a task, and as such cannot isolate the underlying mechanism. Without using a controlled manipulation of perceptual load, visually demanding tasks may also be manipulating other aspects of selective attention (e.g., cognitive load, which is argued to have the opposite effect on attention within the framework of Load Theory), as well as motivational factors such as mood and interest.

The primary aim of the current research was to test whether individuals report fewer appetitive-related thoughts under high compared to low perceptual load. To examine this question, we used Forster & Lavie's (2009) visual search paradigm to measure appetitive-related intrusive thoughts under different levels of perceptual load. The advantage of this task is that perceptual load is manipulated by increasing the number of irrelevant stimuli in the search display while all other aspects remain constant. In particular, participants are required to maintain the same target template in working memory across both levels of

perceptual load, meaning demand is only increased for perceptual and not cognitive control processes under high perceptual load. Previous research has shown that increasing perceptual load in this way does not impact working memory task performance (Lavie, Hirst, De Fockert & Viding, 2004). We used two measures to detect intrusive thoughts, a probe-caught measure (as in Forster & Lavie, 2009) and a self-caught measure. The former measure involves intermittently prompting participants to report on their current thoughts, while the latter measure required participants to report whenever they notice an intrusive thought by pressing the spacebar. Our use of these two measures allowed us to test the effects of perceptual load on thoughts that reach varying levels of meta-awareness. We predicted that the fewer appetitive-related thoughts (on both self-caught and probe-caught measures) would be reported under high compared to low perceptual load.

The secondary aim of this research was to test for potential interactions between perceptual load and state influences on intrusive thoughts. Multiple studies have found that visuospatial distraction tasks (dynamic visual noise and Tetris) reduced craving in participants, even when they were hungry (Steel, Kemps & Tiggemann, 2006; Van Dillen & Andrade, 2016). We hence examined whether the magnitude of the load effect differed as a function of self-reported state measures of hunger, chocolate craving and chocolate liking. While these differences were expected to drive intrusive thoughts under low load, an interesting question was whether perceptual load would be equally effective in reducing thoughts even among very hungry participants, and whether load might even entirely eliminate the influence of individual differences (as has been found in relation to some forms of external distractibility, Forster & Lavie, 2007, although see Forster & Lavie,

2016). Based on this previous research, we predicted that state differences would positively correlate with appetitive-related thoughts under low but not high perceptual load.

Finally, we administered six questionnaires measuring trait characteristics which had been previously associated with craving (Franken & Muris, 2005; Gay, Schmidt, & Van der Linden, 2011; Hill, Weaver & Blundell, 1991; Meule, Lutz, Vögele & Kübler, 2012; Soetens, Braet, Dejonckheere & Roets, 2006). We predicted all trait differences to positively correlate with frequency of appetitive-related thoughts under low but not high perceptual load. However, it has been suggested that trait measures of individual characteristics may only be related to longer term aspects of craving, and not immediate aspects of craving such as intrusive thoughts (Tiggemann & Kemps, 2005). Therefore, these trait measures were collected in addition to our primary research question and have been reported in supplementary information for transparency.

3.2. Method

Participants

Sixty female participants were recruited, aged between 18-35 ($M = 20.72$, $SD = 1.69$) with normal or corrected to normal (e.g., with glasses) vision, either native English speakers or as fluent at both speaking and reading English as a native speaker. The sample was restricted to female participants due to strong gender differences in the experience of craving (Hallam, Boswell, DeVito and Kobera, 2016). The study was run as an undergraduate project at the University of Sussex; participants were recruited via study swaps and a £25 prize draw.

A sample size of sixty was estimated with G*Power using an effect size of .31, the average derived from previous research investigating individual differences in food cravings (Delahanty, Meigs, Hayden, Williamson, & Nathan, 2002; Franken & Muris, 2005; Hill, Weaver & Blundell, 1991; Meule, Lutz, Vogeles & Kubler, 2012; Tiggeman & Kemps, 2005).

The study was approved by the University of Sussex Sciences & Technology Cross-Schools Research Ethics Committee. All participants provided informed consent.

Design

A within subjects 2x2 design was used to assess the frequency of appetitive-related thoughts (either on a self-caught or a probe-caught measure) while participants performed low or high load blocks of the perceptual load task.

Stimuli and procedure

All stimuli were presented using E-prime 2.0 (Schneider, Eschman & Zuccolotto, 2002) on a 13-inch computer screen. The experiment was presented on a black background and all letter stimuli were grey.

The task was adapted from Forster & Lavie (2009). Participants completed both low and high perceptual load blocks of a visual search task whilst suppressing thoughts about chocolate. Each trial started with a central fixation cross displayed for 500 ms, immediately followed by the letter stimuli; the letters appeared for 100 ms, but participants had 2000 ms to respond, after which the display timed-out.

Each stimuli display consisted of six letters arranged in a circle (with a radius subtending 1.6°). Participants searched for a target letter within the circle, either an X or an N, and responded with the corresponding key. Perceptual load was manipulated by varying the setsize of the letter circle. In low perceptual load displays the target letter appeared alongside five small non target o's (subtending $.15^\circ$). In high perceptual load displays the non-targets were angular letters selected from the following: H, K, Z, M and W (irrelevant and target letters subtended $.6^\circ \times .5^\circ$).

There were sixteen blocks in total, eight low and eight high perceptual load blocks in the order LHHLLHHL. Each block had 24 trials. Before the experiment participants completed three slowed down example trials and twelve normal speed practice trials for both perceptual load conditions.

Following the practice trials, participants were exposed to chocolate for a two-minute period; they were asked to focus on the chocolate and imagine eating it in as much detail as possible, such as how it would smell and taste. This was done to increase the potential number of thoughts about chocolate, as being exposed to a food item increases craving (Smeets, Roefs & Jansen, 2009). Chocolate was chosen as it is frequently mentioned by participants as a highly craved food (Richard, Meule, Reichenberger & Blechert, 2017). Then participants completed visual analogue measures of hunger, how much they thought they would like the chocolate and how much they craved the chocolate.

Each question appeared above a 100 mm horizontal line presented on the computer screen, participants dragged the cursor from the midpoint of the scale to indicate their response. The lower end anchor read ‘Not at all’ and the upper end anchor read ‘Extremely’. Participants were then asked two prompting questions to further encourage appetitive-related thoughts (e.g., How do you think the chocolate would taste?). They responded using a free text-box, but these responses were not included in analysis. Finally, before beginning the task, participants were given simple instructions to suppress any thoughts related to chocolate (no guidance was given on how to do this) and focus on the task.

Intrusive thoughts were measured by self-report and probe-caught methods. Participants pressed the space bar each time they caught themselves thinking about chocolate. The self-caught method is subject to participant awareness of their own thoughts (metacognition) which varies between individuals and does not capture intrusive thoughts that are not consciously noticed (Baird, Smallwood, Fishman, Mrazek & Schooler, 2013). Therefore, at the end of each block a thought probe was used to ask what they were thinking about: the task, the chocolate or something unrelated to both. To avoid any influence in difference of quantification of self caught thoughts and to facilitate comparison with a probe-caught measure, the self-caught thought was defined as the percentage of blocks a thought was reported in rather than number of discrete thoughts.

Finally, participants completed a set of questionnaires measuring trait differences that have previously been linked to craving and self-reported their BMI (Body Mass Index).

Trait questionnaire measures

Three Factor Eating Questionnaire (TFEQ; Stunkard & Messick, 1985). The 51 item TFEQ is divided into three factors: restraint, disinhibition and hunger. Only restraint and hunger were analysed.

Dutch Eating Behaviour Questionnaire (DEBQ; Van Strien, Frijters, Bergers & Defares, 1986). Only the 10 item external eating subscale of the DEBQ was used in this experiment.

Sensitivity to punishment and reward Questionnaire (SPSRQ; Torrubia, Avila, Moltó, & Caseras, 2001). This 48-item questionnaire is comprised of two subscales, sensitivity to reward (SR), which reflects behavioural activation and sensitivity to punishment which reflects behavioural inhibition. Only the SR was used in analysis.

Baratt Impulsiveness Scale (BIS 11; Patton, et al, 1995). The 30 item BIS 11 measures three dimensions of impulsivity: attentional; motor and non-planning. Only the overall total impulsivity score was used in analysis.

3.3. Results

Manipulation check

All data can be downloaded from the open science framework (osf.io/8mep7/). All analyses were conducted using IBM SPSS Statistics 24. Analyses of reaction time (RT) and percentage error (PE) rates confirmed that the perceptual load task was successful at increasing task difficulty. Only trials to which a correct response was made were included within RT analyses. RT's were significantly slower under high ($M = 832.62$, $SE = 14.89$) than low perceptual load ($M = 603.68$, $SE = 12.59$), $t(59) = 20.68$, $p < .001$, $d = 2.15$. Percentage error rate was also increased under high ($M = .19$, $SE = .01$) compared to low perceptual load ($M = .06$, $SE = < .01$), $t(59) = 12.13$, $p < .001$, $d = 1.92$. There were also significantly less general task unrelated thoughts under high ($M = 22.29\%$, $SE = 2.88\%$) compared to low perceptual load ($M = 35.21\%$, $SE = 3.80\%$), replicating Forster and Lavie's previous findings (2009), $t(59) = 4.18$, $p < .001$, $d = .50$.

The effect of perceptual load on appetitive-related thoughts

To test whether self-caught and probe-caught appetitive-related thoughts were modulated by perceptual load, a 2 x 2 within subject ANOVA was conducted, contrasting perceptual load (low, high) with measure (self-caught, probe-caught). As predicted, fewer appetitive-related thoughts were reported under high compared to low perceptual load, $F(1, 59) = 37.37$, $p < .001$, $N_p^2 = .39$. There was also a significant main effect of measure, $F(1, 59) = 27.21$, $p < .001$, $N_p^2 = .32$, with fewer appetitive-related thoughts being reported on the probe-caught measure. The interaction between perceptual load and measure was also significant, $F(1, 59) = 14.61$, $p < .001$, $N_p^2 = .20$. Figure 1 suggests that the interaction

reflects a larger effect of perceptual load on the self-caught compared to the probe-caught measure. However, crucially, follow up t -tests showed that perceptual load significantly reduced the percentage of appetitive-related intrusive thoughts for both self-caught, $t(59) = 6.65$, $p < .001$, $d = .92$, and probe-caught measures, $t(59) = 3.45$, $p = .001$, $d = .44$. Mean percentages and standard error are displayed in Figure 1.

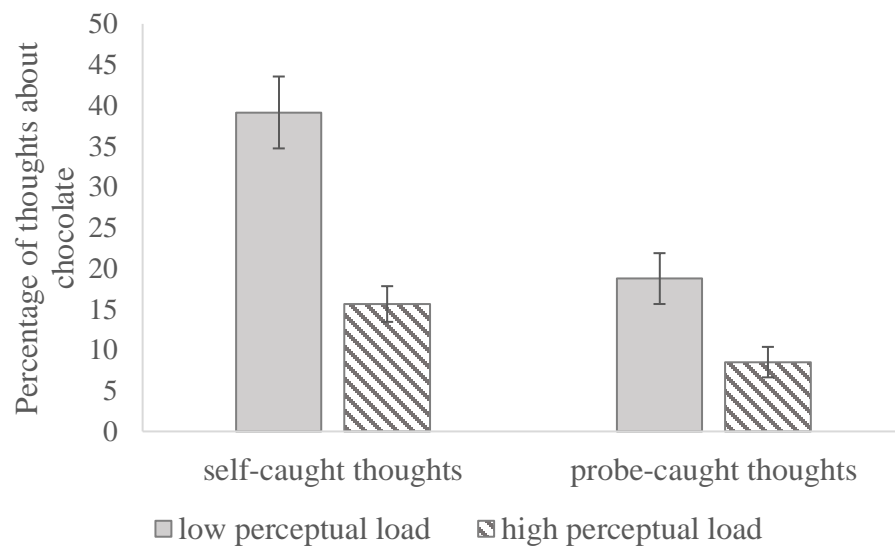


Figure 1: Percentage of self-caught and probe-caught appetitive-related thoughts under low and high perceptual load. Error bars show standard error.

Individual differences

Sample characteristics have been reported in Table 1. In order to test for potential interaction between load effects and hunger, chocolate craving and chocolate liking, we ran one tailed Pearson correlations between these measures and the load effects on self-caught and probe-caught intrusive thoughts. Load effects were calculated as the difference between intrusive thoughts under low and high perceptual load (i.e., low load intrusive thoughts

minus high load intrusive thoughts). As can be seen in Table 1, all three measures correlated significantly for both probe and self-caught thoughts. To further break down this interaction, we examined the correlations between each of these variables and intrusive thoughts in each load condition. As can be seen in Table 2, hunger, chocolate craving and chocolate liking were all positively associated with the appetitive-related intrusive thoughts in low load. However, these correlations were eliminated in high load.

Exploratory analysis of the trait questionnaire measures did not reveal any significant correlations with load effects, all $ps > .088$ (see supplementary table S1).

Table 1

Sample characteristics: mean (SE in parentheses) and range for measures of both state and trait differences.

	State measures			Trait measures					
	Hunger	Craving	Liking	TFEQ_R	TFEQ_D	BIS 11	SR	DEBQ_E	BMI
Mean (SE)	53.58 (4.12)	60.20 (3.58)	67.60 (3.37)	8.77 (.70)	7.13 (.38)	64.57 (1.13)	11.10 (.54)	3.32 (.08)	20.90 (.47)
Range	0.00 – 100.00	0.00 – 100.00	0.00 – 100.00	0.00 – 21.00	2.00 – 15.00	37.00 – 81.00	3.00 – 21.00	1.90 – 5.00	16.02 – 34.17

Note: TFEQ_R = Three factor eating questionnaire, restraint subscale; TFEQ_D = Three factor eating questionnaire, disinhibition subscale; BIS 11 = Baratt Impulsivity total score; SR = Sensitivity to punishment and reward Questionnaire, reward subscale; DEBQ_E = Dutch Eating Behaviour Questionnaire, external eating subscale; BMI = Body Mass Index.

Table 2

One tailed Pearson correlations and 95% bootstrapped confidence intervals between state individual differences, load effect on appetitive -related thoughts and frequency of appetitive-related thoughts reported under low and high perceptual load.

		State Hunger	Chocolate craving	Chocolate liking
Load effect	Self-caught	.40** [.23, .57]	.34** [.15, .54]	.34** [.12, .52]
	Probe-caught	.39** [.23, .53]	.32** [.26, .60]	.31** [.14, .50]
Low perceptual load	Self-caught	.38** [.19, .57]	.36** [.17, .54]	.32** [.11, .51]
	Probe-caught	.38** [.19, .56]	.44** [.26, .62]	.31** [.13, .46]
High perceptual load	Self-caught	.12 [-.12, .35]	.18 [-.05, .40]	.10 [-.14, .30]
	Probe-caught	.02 [-.17, .24]	.05 [-.17, .34]	.03 [-.18, .23]

Note: **Correlation is significant at the .01 level

3.4. Discussion

Our research clearly demonstrates that increasing the level of perceptual load in a task can powerfully reduce appetitive-related intrusive thoughts. There were significantly less thoughts about chocolate when participants were engaged in the high compared to the low perceptual load task. This was evident on both self-caught and probe-caught measures, showing that the effect was not dependent on awareness and/or ability to report the thought. However, the effect was greatest on the self-caught measure, suggesting that the effect of perceptual load increased with higher levels of meta-cognition.

Our results add to the literature on Load Theory by demonstrating that, in addition to reducing awareness of external sensory stimuli and general task unrelated thoughts, perceptual load can reduce the occurrence of even highly salient intrusive appetitive thoughts. An interesting question for future research is whether the effect of perceptual load was primarily on visual intrusive imagery or extended to olfactory imagery (see Kemps & Tiggeman, 2007). Our craving induction method involved participants holding a chocolate bar for two minutes and imagining what it would be like to eat. Whilst internal imagery may have involved multiple senses, the chocolate bar itself was a visual cue. In real world situations where we might encounter appetitive-related cues that might trigger craving episodes, other senses are likely to be involved (e.g., smell). It would be interesting to test whether perceptual load would successfully reduce appetitive-related thoughts in response to multisensory cues (e.g., after tasting the chocolate). Previous research has suggested that perceptual load modulates processing across a variety of sensory domains (olfactory: Forster & Spence, 2018; auditory: Macdonald & Lavie, 2011; and tactile: Dalton, Lavie & Spence, 2009) and processing of external multisensory stimuli (Lunn, Sjoblom, Ward,

Soto-Faraco, & Forster, 2019; Spence & Santangelo, 2009). Therefore, it seems likely perceptual load would similarly reduce interference from multisensory intrusive thoughts; however, this is yet to be tested.

Our findings suggest that Load Theory could be used as a framework to predict situations in which people may be susceptible to appetitive-related thoughts. For example, a person sitting at their desk engaged in a perceptually undemanding task (e.g., writing a simple email) would have spare attentional capacity to process an appetitive-related thought. In this context, the appetitive-related thought would be more likely to capture attention, potentially resulting in subsequent craving and ultimately consumption. Therefore, if the same person sitting at their desk wanted to prevent a appetitive-related thought, they could tailor their activity to be more perceptually demanding (e.g., filing, searching a complex spreadsheet or fine tuning the visual details of a presentation); this action would disrupt the process of food craving at the earliest possible stage. Purposefully engaging in high perceptual load tasks may hence be a useful recommendation to reduce interference from appetitive-related thoughts. This could have particular value to individuals trying to prevent themselves indulging in a craving (e.g., those on a diet). The potential real world applications of Load Theory should be considered in light of what was an initial single experiment study. We observed highly significant within-subjects effects in a large sample, however, further replications of this study are required, particularly in samples beyond that tested in the current study.

Importantly, our findings suggest that perceptual load was effective in reducing appetitive-related thoughts even for individuals who reported high levels of hunger, chocolate specific craving and liking at the start of the experiment. While these ratings were significantly associated with the number of appetitive-related thoughts under low

perceptual load, these individual differences were eliminated under high perceptual load. This finding is in line with previous work on Load Theory showing that perceptual load reduces distraction irrespective of individual differences observed under low perceptual load (Forster & Lavie, 2007). We also extend previous evidence from the eating literature, that a distraction task reduces craving for food in individuals who are hungry (Steel, Kemps & Tiggemann, 2006; Van Dillen & Andrade, 2016). This aspect of our research is important for establishing the usefulness of the task, as in the real world an individual's current state may increase the risk of indulging in an unwanted craving, but our findings suggest a high perceptual load task should still reduce the impact of appetitive-related thoughts.

Exploratory correlations revealed no trait differences in appetitive-related thoughts, even under conditions of low perceptual load. Trait differences comprised of restraint, disinhibition, impulsivity, sensitivity to reward and external eating. All of which have been shown in previous research to be related to craving (Franken & Muris, 2005; Hill, Weaver & Blundell, 1991; Meule, Lutz, Vögele & Kübler, 2012; Soetens, Braet, Dejonckheere & Roets, 2006). However, while an increase of appetitive-related thoughts is thought to coincide with craving for that food (May, Andrade, Kavanagh, & Hetherington, 2012), none of these trait measures have been shown to be specifically related to increased appetitive-related thoughts. Tiggemann & Kemps (2005) found that dietary restraint was related to habitual trait craving but not with state craving (measured by the intensity of a specific craving episode), leading the authors to suggest that restraint may be related to global measures of food craving rather than single episodes. The current study measured intrusive appetitive-related thoughts (which were expected to reflect short-term immediate desire for that food) in response to exposure to a chocolate bar.

A second possibility is that no trait differences were observed due to the primarily healthy-weight homogenous student sample recruited in this study. In future, this research could be extended by investigating whether perceptual load similarly reduces appetitive-related thoughts in more diverse samples, such as those who are currently dieting or even clinical samples. For example, it would be useful to establish whether perceptual load is able to reduce appetitive-related thoughts in overweight and obese populations to the same extent as those with a healthy-weight, as these groups may be a greater risk of experiencing cravings (Delahanty, Meigs, Hayden, Williamson, & Nathan, 2002; Rodin, Manuso, Granger, & Nelbach, 1991). For now, we note promising preliminary evidence that perceptual load was effective at reducing appetitive-related thoughts across individuals, even in those who showed the highest frequency of appetitive-related thoughts.

An advantage of our task is that we were able to directly test whether the number of thoughts produced during the task varied under different levels of perceptual load, rather than relying on a single measure of craving taken after the experiment. However, due to the within subjects design we could not test whether perceptual load had any long term effect on craving or consumption. Van Dillen & Andrade (2016) found that participants choose a healthier snack after playing Tetris, suggesting that a visually distracting task is able to influence actual eating behaviour after completion of the task. As Tetris is also likely to be high in perceptual demand, this implies that a high perceptual load task may also influence subsequent behaviour. In future, it would be useful to test whether perceptual load can reduce unwanted snacking, as this determines whether engaging in tasks high in perceptual load is a worthwhile real-world recommendation.

To summarise, our study clearly shows that perceptual load reduces intrusive appetitive thoughts about chocolate. This suggests Load Theory may be a useful framework

to predict the situations in which individuals may be vulnerable to appetitive-related thoughts, which may then result in craving and unwanted consumption. In addition, engaging in high perceptual load tasks may be a valid strategy to reduce the occurrence of appetitive-related thoughts, even when experiencing high levels of hunger, craving or liking for the specific food item.

3.5. Supplementary information

Table S1

One tailed Pearson correlations and 95% bootstrapped confidence intervals between trait questionnaire measures and load effect on intrusive thoughts.

	TFEQ_D	TFEQ_R	BIS 11 Total	S Reward	DEBQ_E	BMI
Self-caught Chocolate	.14	-.01	-.04	.09	-.01	-.16
thoughts	[-.10, .38]	[-.30, .27]	[-.31, .25]	[-.20, .38]	[-.25, .25]	[-.37, .09]
Probe-caught chocolate	.12	.14	.04	.18	-.02	.02
thoughts	[-.12, .34]	[-.04, .34]	[-.20, .25]	[-.09, .40]	[-.24, .23]	[-.17, .26]
Probe-caught Task	-.03	.12	.11	-.07	.04	.08
unrelated thoughts	[-.26, .21]	[-.13, .36]	[-.16, .39]	[-.30, .20]	[-.15, .25]	[-.15, .36]

Note: TFEQ_D = Three factor eating questionnaire, disinhibition subscale; TFEQ_R = Three factor eating questionnaire, restraint subscale; BIS 11 Total = Baratt Impulsivity Questionnaire, total score; S Reward = Sensitivity to punishment and reward Questionnaire, reward subscale; DEBQ_E = Dutch Eating Behaviour Questionnaire, external eating subscale; BMI = Body Mass Index.

3.6. Interim summary

The combined results of paper one and two confirmed that both external and internal food-related stimuli were strongly modulated by perceptual load. Therefore, the research conducted so far in this thesis supported the first aspect of the proposed perceptual load theory framework: that multiple aspects of food-related cognition are dependent on basic perceptual resources. Given that both attentional bias and food-related thoughts have been linked to craving and overconsumption (e.g., Field & Cox, 2008; see Section 1.3 for discussion), perceptual load has numerous potential real-world applications, particularly in regard to those trying to reduce their intake.

Therefore, the next step in testing a comprehensive perceptual load theory framework of eating behaviour was to extend its effects to food consumption. As perceptual load had been previously shown to reduce processing across multiple sensory modalities (e.g., Forster & Spence, 2018; Macdonald & Lavie, 2011; Murphy & Dalton, 2016), it was fully expected to modulate awareness of flavour in paper three. Due to feasibility constraints of manipulating both flavour and perceptual load within the same task, a mixed-subjects design was used in paper three, reducing statistical power to investigate individual differences (as was done in paper one and two). Therefore, key trait differences were instead controlled for in analysis. Several small changes were made to the visual search task to allow for consumption (e.g., the task did not require a hand movement for response in Experiment 2). However, similar alterations had been made previously in perceptual load studies and were not expected to undermine the effectiveness of the task.

4. Paper three: Flavour awareness is not reduced by perceptually demanding tasks: implications for ‘mindless’ eating.

Jenny Morris, Sophie Forster and Martin R. Yeomans

Abstract

Previous research has indicated that inattentive eating may, in part, be underpinned by a lack of flavour awareness. Perceptual load is a robust manipulation of attention, known to powerfully reduce interference from and awareness of task irrelevant stimuli across a range of sensory modalities. The aim of this study was to test whether perceptual load also reduced awareness of flavour, and if this effect was associated with inattentive eating. Across two experiments, one hundred and fifty female participants completed a visual search task while consuming salted or unsalted crisps. Load was manipulated between subjects by increasing set-size: under low perceptual load, participants searched for a target (X or N) which was presented simultaneously with small circular non-target letters whereas under high perceptual load five angular non-target letters were used. In Experiment 2 an additional ‘no load’ control condition was included. The results showed that participants consumed more salted compared to unsalted crisps, under both levels of perceptual load. Post experiment sensory ratings were also unaffected by perceptual load. Our results imply that lack of flavour awareness may not be the mechanism behind inattentive eating. Therefore, inattentive eating interventions should focus on factors other than the sensory characteristics of food.

4.1. Introduction

The perception of the flavour of a food or drink may influence intake in multiple ways. On the one hand, palatability, the hedonic evaluation of flavour, is considered to be one of the major drivers of increased food consumption (Yeomans, 1998). Studies have consistently shown that short term food intake increases in response to increased palatability (see Sørensen, Møller, Flint, Martens, & Raben, 2003, for a review). This overconsumption may contribute towards weight gain and obesity, particularly as palatable foods tend to be higher in energy density, fat, and sugar (Drewnowski, 1998), and are often consumed in the absence of hunger (de Castro, Bellisle, Dalix, & Pearcey, 2000). On the other hand, lack of flavour awareness may also result in increased food consumption. The ‘mindless’ eating literature has frequently suggested that eating behaviour is influenced by external factors, such as distraction, resulting in reduced awareness of the food being consumed (Ogden et al., 2013). Therefore, while palatable food may increase consumption, lack of flavour awareness may lead to the same outcome.

Previous research on inattentive eating

Eating while distracted is a common issue cited by those struggling to control their intake. In recent years, the effect of television viewing on intake has attracted research interest. Numerous studies have indicated that eating while being distracted by television increases intake (Bellisle, Dalix, & Slama, 2004; Bellissimo, Pencharz, Thomas, & Anderson, 2007; Blass et al., 2006; Braude & Stevenson, 2014; Hetherington, Anderson, Norton, & Newson, 2006; Martin, Coulon, Markward, Greenway, & Anton, 2008; Ogden et al., 2013; Temple, Giacomelli, Kent, Roemmich, & Epstein, 2007). Similar studies have also found that intake can be increased by simultaneously hearing a story (Bellisle & Dalix,

2001; Long, Meyer, Leung, & Wallis, 2011), listening to music (Stroebele & de Castro, 2006), or playing a computer game (Oldham-Cooper, Hardman, Nicoll, Rogers, & Brunstrom, 2010). This has typically been tested by comparing the amount consumed while attention is engaged in the task, to the amount consumed with no task. A meta-analysis of studies, which included a variety of distraction tasks, concluded that inattentive eating was associated with a moderate increase in immediate intake (Robinson et al., 2013).

Evidence has also been found for predictable individual differences in the extent to which people exhibit inattentive eating. Most inattentive eating research has focused on restrained eaters, defined as people with a tendency towards dieting, who have been shown to overeat when engaged in a simultaneous task (Bellisle & Dalix, 2001; Boon, Stroebe, Schut, & Ijntema, 2002; Ward & Mann, 2000). The boundary model suggests that restrained eaters are particularly vulnerable to over-eating in this context because they are disrupted from monitoring their diet goals (Herman & Polivy, 1984). It has also been argued that maintaining a dieting goal is cognitively demanding, further increasing vulnerability to inattentive eating (Stroebe, Mensink, Aarts, Schut, & Kruglanski, 2007). However, the relationship between dietary restraint and increased intake in response to distraction has not been found consistently. For example, Robinson et al., (2013) found that both restrained and unrestrained eaters increased immediate food intake to a similar degree.

Recent studies have attempted to identify the mechanisms which may underlie the inattentive eating effect. Reduced awareness of interoceptive cues is one possibility which has been suggested in multiple studies. Blass et al (2006) found that although those watching television ate significantly more food than a control group the two groups had comparable ratings of appetite, suggesting that different amounts of food generated the

same interoceptive experience, with increased food intake in the TV watching condition not causing greater satiation. Moray, Fu, Brill & Mayoral (2007) also concluded that estimates of food intake were less accurate if participants were watching television while eating. Braude & Stevenson (2014) found that participants watching television needed to consume more food in order to achieve the same fullness ratings as when they were not watching television, suggesting they were less responsive to interoceptive cues. In the same study, Braude & Stevenson (2014) investigated other potential mechanisms of inattentive eating. They gave participants either a single snack food or four different snack foods, with or without a television program to watch. Usually when presented with a single food item participants will develop sensory specific satiety, a phenomenon whereby liking of a food decreases as it is eaten relative to uneaten foods, as the consumer habituates to the experience. Alternatively, if participants are allowed to alternate between multiple food items, liking is maintained (Rolls, Rolls, Rowe, & Sweeney, 1981). Braude & Stevenson (2014) found that liking ratings changed less for participants who had eaten a single food snack while watching television compared to when they didn't watch television, and this was also associated with higher food intake in the television condition. This implies that sensory specific satiety, which usually acts as a natural stopping signal by reducing liking for a specific food, was disrupted by the distraction of the television. This finding was previously observed by Brunstrom & Mitchell (2006), who found that undistracted participants reported reduced desire to consume the food they'd been eating and increased desire to eat a different food, but participants who played a computer game while eating showed no difference between their rated desires to eat either food item. However, it is unclear why distraction might disrupt the effect of sensory specific satiety.

Reduced flavour awareness as a potential mechanism of inattentive eating

A potential explanation for the increased intake observed in inattentive eating studies is that participants were less aware of the food's flavour when they were distracted. Van der Wal & van Dillen (2013) tested the effect of task load, which was manipulated via a digit span task, on flavour perception (the authors used the word taste, but we are using the word flavour as their manipulation better fits onto the way we have defined flavour here) of sour, sweet, and salty, solutions and food items. Under high task load, participants reported all flavour solutions as less intense, consumed fewer crackers spread with salty butter, and added less grenadine syrup to lemonade. This is one of the few studies to directly test whether distraction reduces flavour perception. The authors suggest that the reduced sensory experience means that people require more food to achieve an optimal flavour experience. Further research by Hoffmann-Hensel, Sijben, Rodriguez-Raecke & Freiherr (2017) found that a similar task reduced the perceived intensity of low calorie food odours, but not high calorie food odours, reflected on both behavioural and neuronal measures. Participants were presented with food odours while simultaneously memorising one or seven string consonant combinations, and then rated the intensity of the odour on a visual analogue scale after each trial. Lower reported intensity of low calorie food odours presented during high compared to low load trials was accompanied by lower activity in bilateral orbitofrontal and piriform cortices, whereas for high calorie odours there was no difference in bilateral orbitofrontal cortices activation under either level of load. While these studies are promising, and the few which directly test whether distraction reduces flavour perception, they do not assess the relationship between flavour perception and inattentive eating.

As previously mentioned, distraction increases simultaneous intake, but it also increases intake later on in the day (Robinson et al., 2013). This effect occurs because participant's memory of the meal has been affected by the distraction task. Higgs (2015a) found that participants report lower 'vividness of the meal' ratings when they consumed the meal while engaged in a distracting task (playing a computer game). In contrast, participants who ate while focusing attention on the food (audio instructions) reported higher 'vividness of the meal' ratings (Robinson, Kersbergen, & Higgs, 2014). While 'vividness' could refer to several aspects of the meal, it is likely flavour was part of the memory representation (Morin-Audebrand et al., 2009, have shown that flavour is an important aspect of food memory). This suggests that any effect of distraction on flavour perception could also impact the memory for that flavour, which may in turn influence subsequent intake.

Perceptual load theory

Given its potential contribution towards over-eating, it is clearly important to establish whether distraction reduces awareness of flavour. We will test this, utilising the perceptual load theory of selective attention. A large body of evidence in support of the Load Theory of attention (e.g., Lavie, 2005, 2010) highlights that the extent to which task irrelevant stimuli are processed is powerfully determined by the level of perceptual load in the task – increasing perceptual load typically reduces or eliminates task irrelevant processing. Load theory would hence predict that, if load modulates processing of food stimuli in the same manner as other stimuli, reduced flavour awareness and inattentive eating should only occur during high load, when attentional capacity has been exhausted by the task. We have previously used perceptual load manipulations to successfully reduce

distraction by food stimuli and intrusive thoughts about food (Morris, Yeomans & Forster, 2020; Morris, Ngai, Yeomans & Forster, 2020). However, perceptual load has not been applied to the consumption aspect of eating behaviour. The majority of research into load theory has focused on the visual domain, but perceptual load has also been shown to reduce processing of stimuli in multiple sensory domains including olfactory (Forster & Spence, 2018), auditory (Macdonald & Lavie, 2011) and tactile (Murphy & Dalton, 2016). Therefore, it appears likely that a high load task would interfere with multiple aspects of eating behaviour.

The current research

The current research directly tested the role of flavour awareness in over-eating using perceptual load theory. Participants were provided with both palatable and unpalatable foods while they were simultaneously engaged in the perceptual load task. Awareness of flavour should be reflected by increased consumption of the palatable food relative to the less palatable, and we predicted that this increased consumption of the palatable food should be stronger in the low perceptual load task. A reduced or eliminated difference in intake between the different foods would suggest that the perceptual load task interferes with awareness of flavour. We also took memory ratings for the sensory characteristics of the food to see if any effects of the perceptual load task are further evidenced by poorer recall of the differences in flavour of the two test foods. If awareness of flavour contributed towards inattentive over-eating, then the reduced difference in intake should be correlated with increased overall intake.

Due to the large number of individual difference characteristics known to influence eating behaviour, we administered a range of questionnaire measures after the task to

control for any potential confounding effects of individual eating patterns. Individual difference measures were chosen based on those identified from the literature as commonly used in food intake studies, and therefore likely to influence consumption. As previously mentioned, restraint is thought to be most directly relevant to inattentive eating, and so the Three Factor eating Questionnaire was included. The questionnaire also measures disinhibition, a tendency towards uncontrolled eating, which is known to affect intake (Bryant, King, & Blundell, 2008; Ouwens, Van Strien, & Van Der Staak, 2003).

Participants who are both low in restraint and high in disinhibition have also been shown to be over-responsive to palatability manipulations (Yeomans, Tovey, Tinley, & Haynes, 2004). External eating has also been shown to influence intake, especially in response to external cues such as television with food commercials (Van Strien, Herman, & Anschutz, 2012). As palatability is another external cue, we included the Dutch eating behaviour Questionnaire as an individual difference measure. Finally, impulsivity is strongly linked to over-eating (Meule, 2013; Mobbs, Crépin, Thiéry, Golay, & Van der Linden, 2010). Therefore, we used both the Baratt Impulsiveness scale and the Sensitivity to reward Questionnaire to control for this potential modulator of intake.

Our primary aim in Experiment 1 was to test whether awareness of flavour is modulated by perceptual load. We also tested whether perceptual load induced inattentive eating, which would be demonstrated by higher overall intake for participants engaged in the high perceptual load task compared with those who complete the low perceptual load task. Individual differences were included in intake analyses to control for their potential influence.

4.2. Experiment 1

4.2.1. Methods

Participants. Sixty female participants were recruited, aged between 18-35 ($M = 19.42$, $SD = 2.47$) with normal or corrected to normal (e.g. with glasses) vision, either native English speakers or as fluent at both speaking and reading English as a native speaker. The study was run primarily on undergraduate students at the University of Sussex; participants were provided with financial compensation or course credit. The study was approved by the University of Sussex Sciences & Technology Cross-Schools Research Ethics Committee and complied fully with BPS ethical standards.

A Bayesian sample size estimate was conducted using data from unpublished research conducted in our laboratory which investigated the effect of perceptual load on intake of fresh and stale popcorn. However, that manipulation of palatability failed to increase intake in any condition, meaning that the non-significant effect of perceptual load on intake was inconclusive, probably because of the subtlety of the flavour manipulation. Consequently, we changed the test foods to salted and unsalted crisps for the current experiment, and we confirmed the effectiveness of this manipulation with a pilot taste test ($n = 6$). We were interested in participant's pleasant and saltiness ratings after they tasted the crisps to ensure there was a clear palatability difference between the foods. On 100pt visual analogue scales, there was a 35.5pt and 56.5pt difference, respectively. We powered the current study to detect a sensitive null effect of load on intake using Bayesian statistics; if the current experiment also yielded null results, Bayesian tests of sensitivity would allow us to determine the strength of evidence for both the null and alternative hypotheses. We derived a population standard error of .67 and an upper bound of 2.51 from our previous

study, and used Dienes (2014) method of estimating sample size with the online Bayes factor calculator, to obtain a Bayesian sample size estimate of sixty-one participants.

Experimental Design. A mixed 2x2 design was used. Level of perceptual load was manipulated between subjects, and participants were randomly assigned to either the low or high perceptual load condition. Food palatability was manipulated within subjects: all participants received both salted and unsalted crisps to consume throughout the task in alternation.

Stimuli and procedure. All testing was carried out in experimental cubicles at the University of Sussex Ingestive behaviour laboratory. Participants sat at a computer with a placemat in front of it. They consumed test foods when instructed, while engaged in either the low or high perceptual load task.

All stimuli were presented on a 13.5-inch computer screen using E-prime 2.0 (Schneider, Eschman, & Zuccolotto, 2002). The experiment was presented on a grey background and all letter stimuli were black. Participants completed either low or high perceptual load blocks of a visual search task using an adaptation of the procedure from Forster & Lavie (2008). Each trial started with a central fixation cross displayed for 500 ms, immediately followed by the letter stimuli. The letters appeared for 100 ms, but participants could respond until the display timed-out after 2000ms. The next trial began after the 2000ms response window had finished regardless of when a response was given to ensure that participants completing the low load version of the task (where responses are typically quicker) spent the same length of time carrying out the task (so that they were exposed to food for the same length of time).

Each stimuli display consisted of a circle of six letters. Participants searched for a target letter within the circle, either an X or an N, and responded with the corresponding key. Perceptual load was manipulated by varying the set-size of the letter circle. The letter circle had a 2.4 degree radius (each letter subtending 1.2 by 1 degree). In the high-load condition the non-target letters in the circle (selected at random from H, K, M, Z, W, V) were placed randomly around the circle. In the low load condition, the non-target letters were all small o's measuring 0.19 degrees.

Participants completed eight blocks in total, and each block had 60 trials. Before the experiment participants completed three slowed down example trials and twenty four normal speed practice trials for the appropriate level of load in their condition. A baseline hunger rating was then taken using a 0-100 visual analogue scale (VAS), embedded within nine other irrelevant mood ratings which were intended to disguise the hunger rating and received no further analysis. Each VAS scale was presented as a 100mm horizontal line on the computer screen. Each mood question appeared above the line with a lower end anchor of 'Not at all' and an upper end anchor of 'Extremely'. Participants dragged the cursor from the midpoint of the scale to indicate their current mood. Qualtrics was used to collect these ratings (Qualtrics, Provo, UT). Hunger was not explicitly manipulated, instead all testing was carried out between 10-12am or 3-5pm to avoid testing at mealtimes (when participants might be particularly hungry).

Participants were given four bowls of pre-weighed crisps to consume during the experiment: two bowls of salted crisps (Walkers Ready Salted) and two bowls of unsalted crisps (Walkers Salt & Shake). Although there were only two different food flavours, four bowls were used to disguise the aim of the experiment. Each bowl contained 50 grams of

crisps (approximately two standard bags). The crisps were presented on a tray and placed to the side of the experimental setup. Each bowl was labelled with a three digit code, and participants were instructed to place a different bowl on the placemat in front of the computer before the start of each block. They were instructed that they should eat at least one crisp from this bowl during the block, but that they could eat as many as they liked. They were specifically told to eat the first crisp at the start of the block once the first trial had appeared on the screen – this was to ensure they began eating once already engaged in the perceptual load task. They were also provided with water throughout the task and reminded to drink in the breaks (to minimise drinking during experimental blocks).

Participants always consumed the crisps in an alternating order of salted and unsalted. Salted crisps were always consumed first to make the potential difference between amounts of salted and unsalted crisps eaten larger (this ‘contrast effect’ was found in previous unpublished data from the Sussex Ingestive Behaviour Laboratory). The total weight of the bowl and crisps was weighed before and after testing to allow intake to be calculated.

Following the main task, participants completed sensory ratings for the food consumed. First, they rated the crisps on how pleasant, salty, and sweet they remembered them being on visual analogue scales. The sweet rating was an irrelevant filler rating that was not included in analysis. The structure and anchor labels of the visual analogue scales were the same as that described for the mood ratings. Once they had completed the ratings, they were given four samples of the same crisps they had consumed – relabelled with different three digit codes (so that their memory wouldn’t influence their taste experience). Then they tasted one crisp from each bowl and made the same ratings again. Ratings were

presented in the following order: pleasant, salty and sweet. Each sample was rated in a random order. Participants were instructed to take a sip of water between each sample. The final rating asked how different the samples tasted compared to what they remembered; participants responded using the same 100mm VAS scale with a lower end anchor of ‘Not at all different’ and a upper end anchor of ‘Extremely different’.

Finally, participants completed a set of questionnaires measuring individual difference characteristics. The researcher also measured participant’s height and weight at the end of the experiment using a stadiometer with an integrated height measure, before thanking and debriefing them.

Questionnaire measures. We conducted a search of the literature to identify questionnaire measures thought to measure separate constructs related to eating behaviour, and which would be predicted to influence either responsiveness to palatable food or susceptibility to inattentive eating. We expected all questionnaire measures to correlate with either the difference in intake of salted compared to unsalted crisps or increased intake under high perceptual load.

Measures of eating attitude.

Three Factor Eating Questionnaire (TFEQ; Stunkard & Messick, 1985). The 51 item TFEQ is divided into three factors: restraint, disinhibition and hunger. Restrained eaters have been previously shown to be more susceptible to inattentive eating (Bellisle & Dalix, 2001). Disinhibited eaters have both a tendency towards opportunistic eating (Bryant et al., 2008) and are more responsive to palatable food (Yeomans et al., 2004)

Dutch Eating Behaviour Questionnaire (DEBQ; Van Strien, Frijters, Bergers & Defares, 1986). Only the 10 item external eating subscale of the DEBQ was used in this experiment. Previous research has found that external eating is linked to increased consumption in laboratory studies (Nijs, Muris, Euser, & Franken, 2010; Wardle et al., 1992). This is thought to be due to people scoring highly on this scale being more responsive to external appetite cues (of which one is palatability). However, there is little direct evidence of this relationship.

Measures of impulsivity

Sensitivity to punishment and reward Questionnaire (SPSRQ; Torrubia, Avila, Moltó, & Caseras, 2001). This 48-item questionnaire comprised of two subscales, sensitivity to reward (SR) which reflects behavioural activation and the sensitivity to punishment which reflects behavioural inhibition. Sensitivity to reward has been found to be related to food craving and increased body weight (Franken & Muris, 2005). In addition, individuals scoring highly on this trait have shown increased neural activity in the areas of the brain associated with food reward, in response to exposure to palatable food (Beaver et al., 2006).

Baratt Impulsiveness Scale (BIS 11; Patton, et al, 1995). The 30 item BIS 11 measures three dimensions of impulsivity: attentional; motor and non-planning. The attentional and, to a lesser extent, motor subscales of the Baratt impulsiveness scale have been most reliably associated with overeating (Meule, 2013).

4.2.2. Results

Traditional analyses for both experiments were conducted using IBM SPSS Statistics 24.

Manipulation check. Reaction times on trials where a correct response was made were significantly slower in the high perceptual load condition ($M = 763.71$, $SE = 21.87$) than in the low perceptual load condition ($M = 567.44$, $SE = 14.68$): $t(58) = 7.45$, $p < .001$, $d = 1.96$. Similarly, accuracy was lower in the high perceptual load condition ($M = .81$, $SE = .01$) compared to the low perceptual load condition ($M = .95$, $SE = .01$): $t(58) = 8.85$, $p < .001$, $d = 2.32$. Slower reaction times and lower accuracy rate under high perceptual load confirmed our manipulation of perceptual load. There were no relationships between reaction time on the task and intake under low, $r(58) = -.04$, $p = .419$ or high perceptual load conditions, $r(58) = -.13$, $p = .249$. The same pattern of results was observed for accuracy, which was unrelated to intake in both low, $r(58) = .08$, $p = .335$, and high perceptual load conditions, $r(58) = .07$, $p = .367$. This suggests participants did not disengage from the task in order to consume more crisps.

Intake data. To test whether flavour awareness was modulated by perceptual load, we measured the amount eaten, in grams, of the unsalted and salted crisps. Four bowls were presented to participants, two unsalted and two salted: intake of unsalted and salted crisps was averaged across the two bowls (we did not analyse intake from each individual bowl). We contrasted intake as a function of flavour (salted or unsalted) and level of perceptual load (low or high) using a 2x2 mixed subjects ANCOVA. The following covariates were included in analysis: Baseline hunger, TFEQ Restraint subscale, TFEQ Disinhibition subscale, BIS 11 overall score, SPSRQ Reward subscale, DEBQ External eating subscale

and BMI. All covariates were mean centred before being included in analysis, as recommended by Schneider, Avivi-Reich, and Mozuraitis (2015) for designs containing a within subject factor. Figure 1 presents mean intake across conditions.

There were marginally significant interactions between restraint, $F(1, 51) = 3.79$, $p = .057$, $N_p^2 = .07$, Sensitivity to Reward, $F(1, 51) = 4.02$, $p = .050$, $N_p^2 = .07$, and the type of crisp consumed. There were no other significant effects of covariate, all $ps > .182$. As predicted, after controlling for covariates, intake of salted crisps was higher than intake of unsalted crisps, $F(1, 51) = 72.17$, $p < .001$, $N_p^2 = .59$, confirming the palatability manipulation increased intake. However, contrary to our central hypothesis, there was no effect of perceptual load on intake, $F(1, 51) = .35$, $p = .555$, $N_p^2 = .00$. The interaction between perceptual load and intake was also non-significant, $F(1, 51) = .06$, $p = .814$, $N_p^2 = .00$. The null interaction indicates that the salted -unsalted crisp intake difference under low perceptual load ($M = 12.77$, $SE = 1.99$) and perceptual load ($M = 13.58$, $SE = 2.71$) were similar.

To ensure we hadn't missed subtler effects of load, raw intake scores of salted and unsalted crisps eaten were converted to percentage of total intake scores. The pattern of results was the same as the raw intake score analysis. Participants consumed more salted ($M = 66.33\%$, $SE = 2.38$) than unsalted crisps ($M = 33.67\%$, $SE = 2.38$) under low perceptual load; they again consumed more salted ($M = 63.86\%$, $SE = 2.33$) than unsalted crisps ($M = 36.14\%$, $SE = 2.33$) under high perceptual load. There was a significant main effect of crisp type on intake, $F(1, 58) = 82.38$, $p < .001$, $N_p^2 = .59$, and no interaction between crisp type and load condition, $F(2, 58) = .55$, $p = .461$, $N_p^2 = .01$.

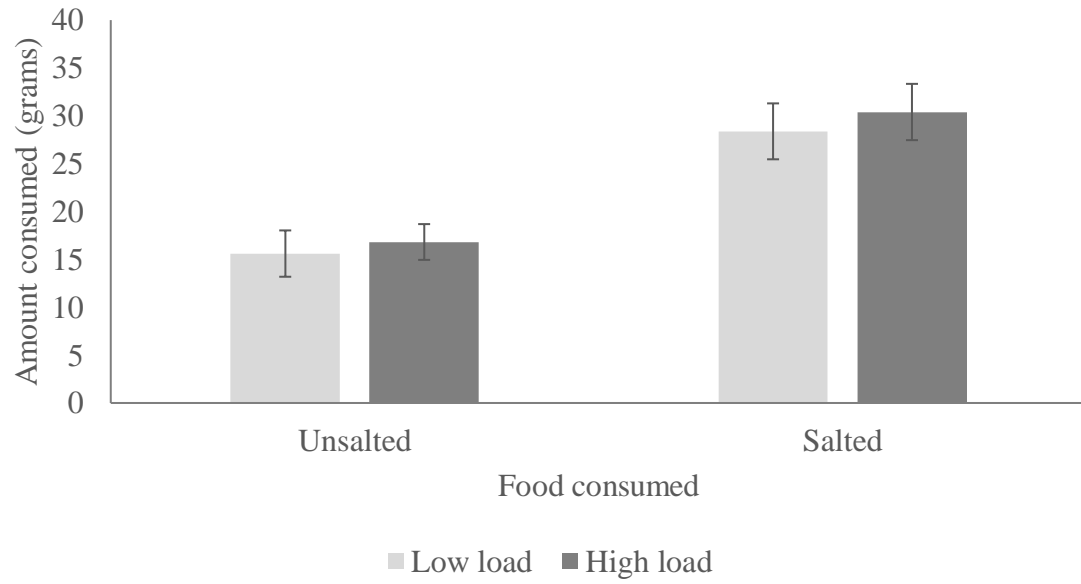


Figure 1: Amount of salted and unsalted crisps consumed under low and high perceptual load in Experiment 1.

Memory ratings. While intake was our primary measure of flavour awareness, we also collected self-reported memory ratings immediately after the perceptual load task had been completed. Figure 2 presents mean visual analogue rating for both pleasant and salty ratings across conditions.

Pleasant ratings. As predicted, pleasant memory ratings were higher for salted crisps than unsalted crisps, $F(1, 58) = 22.55, p < .001, N_p^2 = .28$, confirming that, from memory, participants preferred salted crisps to unsalted crisps. There was no effect of perceptual load on pleasant memory rating, $F(1, 58) = 2.64, p = .109, N_p^2 = .04$. The interaction between crisp type and perceptual load was also non-significant, $F(1, 58) = 2.26, p = .138, N_p^2 = .04$.

Salty ratings. Similarly, salty memory ratings were higher for salted crisps than unsalted crisps, $F(1, 58) = 23.27, p < .001, N_p^2 = .29$, confirming that, participants remembered that the salted crisps tasted saltier. There was a marginally significant effect of load on this salty memory rating, $F(1, 58) = 3.62, p = .06, N_p^2 = .06$: saltiness ratings tended to be higher overall under low perceptual load than under high perceptual load. The interaction between load and flavour was non-significant, $F(1, 58) = 1.36, p = .248, N_p^2 = .02$.



Figure 2: Pleasant and salty memory ratings of unsalted and salted crisps under low and high perceptual load in Experiment 1.

Taste ratings. Figure 3 presents mean visual analogue ratings for both pleasant and salty ratings made for the actual crisps after the memory ratings.

Pleasant ratings. As predicted, pleasant taste ratings were higher for salted crisps than unsalted crisps, $F(1, 58) = 94.47, p < .001, N_p^2 = .62$, confirming that, after tasting, participants thought salted crisps were more pleasant than unsalted crisps. There was no effect of perceptual load condition on pleasant taste rating, $F(1, 58) = .56, p = .458, N_p^2 = .01$, and the interaction between load and flavour was not significant, $F(1, 58) = .15, p = .700, N_p^2 = .003$.

Salty ratings. As predicted, salty taste ratings were higher for salted crisps than unsalted crisps, $F(1, 58) = 174.92, p < .001, N_p^2 = .75$. There was no effect of perceptual

load condition on salty memory rating, $F(1, 58) = .24$, $p = .624$, $N_p^2 = .00$, and the interaction between load and flavour was non-significant, $F(1, 58) = 2.09$, $p = .154$, $N_p^2 = .04$.

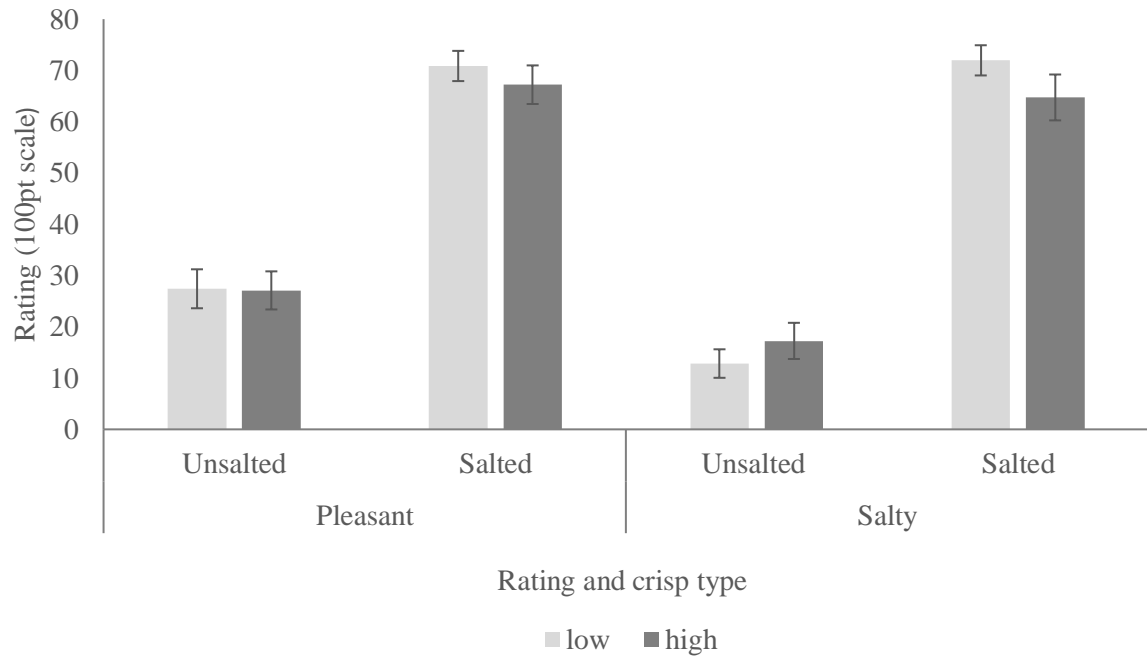


Figure 3: Pleasant and salty taste ratings of unsalted and salted crisps under low and high perceptual load in Experiment 1.

Sample characteristics. Table 1 shows the individual characteristics of the sample for Experiment 1, split by the condition that participants were allocated to. Independent *t*-tests were carried out to check for group differences. Individuals did not significantly differ between load conditions on any of the individual difference traits measures displayed in table 1, all *ps* > .123.

Table 1: Mean characteristics of the sample, across load conditions, for Experiment 1. Standard errors are reported.

	Hunger	TFEQ_R	TFEQ_D	BIS11	SR	DEBQ_E	BMI
	Total						
Low	57.67	6.50	7.47	60.07	10.63	3.30	21.80
load	(4.03)	(.86)	(.60)	(1.41)	(.64)	(.08)	(.60)
High	52.67	7.33	6.53	59.67	11.70	3.10	21.74
load	(4.06)	(1.00)	(.49)	(1.31)	(.79)	(.10)	(.64)

Note: Hunger = Baseline self-reported hunger; TFEQ_R = Three factor eating questionnaire, restraint subscale; TFEQ_D = Three factor eating questionnaire, disinhibition subscale; BIS 11 = Baratt Impulsivity Questionnaire total score; SR = Sensitivity to punishment and reward Questionnaire, reward subscale; DEBQ_E = Dutch Eating Behaviour Questionnaire, external eating subscale, BMI = Body Mass Index.

4.2.3. Discussion

The key finding from Experiment 1 was the lack of load effect on flavour awareness. Participants consumed more and gave higher sensory ratings for the palatable food compared to the unpalatable food in both low and high perceptual load conditions. As this result was demonstrated on both intake and memory measures, our findings suggest that perceptual load does not affect immediate or subsequent flavour awareness. This was contrary to our hypothesis and the suggestions of previous literature.

4.3. Experiment 2

Overall intake in Experiment 1 was surprisingly low. One possibility was that the task was too demanding to allow for the hand movement of picking up crisps—which could have masked any differences in intake. Therefore, the second experiment adapted the task to be hands free, so that both of the participants hands were available to pick up the food. As in previous perceptual load research, we did not include a control condition in Experiment 1. The demand in the low perceptual load task is considered to be minimal and therefore allows for processing of environmental stimuli to take place. However, as we applied perceptual load in a novel context, it was possible that even minimal perceptual load was sufficient to influence eating behaviour. Therefore, we added a control condition to Experiment 2, where the task involved no perceptual load. This comparison is more similar to previous inattentive eating research, which has compared the effect of a distraction task to the effect of no task.

4.3.1. Method

Participants. Ninety participants aged between 18-35 years ($M = 20.6$, $SD = 4.13$) participated in Experiment 2. All other participant details were identical to Experiment 1.

Experimental Design. A mixed 3x2 design was used. As in Experiment 1, food palatability was manipulated within subjects. Level of perceptual load was manipulated between subjects, and participants were randomly assigned to either a no, low or high perceptual load condition.

Stimuli and Procedure. All stimuli and procedure were identical to Experiment 1, except the adaptation of the task to allow the trial response to be hands free.

Instead of responding at the end of every trial as in Experiment 1, participants were instructed to count the number of target letters that appeared in the letter circle. The target letter was X. They responded to a probe question at the end of each block and typed in the number of target letters they had seen. A target letter appeared on 10% of all trials across the experiment, randomly distributed between blocks.

An additional question was added to both the memory ratings that followed the perceptual load task. After making ratings for how pleasant, salty and sweet they found the samples, participants were asked to rate how much of the sample they recalled eating. All details of this extra visual analogue scale were the same as those described for Experiment 1 except that the wording of the question anchors was changed: the lower end anchor was 'one of the crisps' and the upper end anchor was 'all of the crisps'.

4.3.2. Results

Manipulation check. Accuracy rate was significantly lower in the high perceptual load condition ($M = 36.25\%$, $SE = 4.04$) than in the low perceptual load condition ($M = 77.5\%$, $SE = 3.19$): $t(58) = 8.02$, $p < .001$, $d = 1.89$, thus, confirming the increase in task difficulty and effectiveness of our perceptual load manipulation. There were no relationships between accuracy and intake under low, $r(88) = -.07$, $p = .353$, or high perceptual load conditions, $r(88) = .06$, $p = .379$. Therefore, suggesting participants were not disengaging in the task in order to consume more crisps.

Intake data. As in Experiment 1, we tested whether flavour awareness was modulated by perceptual load by comparing the intake of unsalted and salted crisps. Flavour (salted or unsalted) and level of perceptual load (low, high, or none) were entered into a 2 x 3 mixed subjects ANCOVA. The same mean centred covariates used in Experiment 1 were included in analysis. Figure 4 presents mean intake of unsalted and salted crisps, across the three load conditions.

As in Experiment 1, restraint, $F(1, 80) = 5.82$, $p = .018$, $N_p^2 = .07$, and sensitivity to reward, $F(1, 80) = 3.82$, $p = .054$, $N_p^2 = .05$, significantly interacted with type of crisp consumed. There were no other significant covariate effects, all $ps > .127$. After controlling for covariates, crisp type had a significant effect on intake. As predicted, intake of salted crisps was higher than intake of unsalted crisps, $F(1, 80) = 128.41$, $p < .001$, $N_p^2 = .62$, confirming that the palatability manipulation increased intake. Unlike in Experiment 1, there was a significant main effect of load on intake, $F(2, 80) = 4.11$, $p = .020$, $N_p^2 = .09$. Bonferroni corrected pairwise comparisons showed that intake was significantly higher in the high perceptual load compared to the control condition, $p = .028$. Intake was also higher

in the low perceptual load compared to the control condition, although this difference was marginally significant, $p = .086$. There was no difference between intake in the low and high perceptual load conditions, $p = 1.00$. The interaction between load and intake was also significant, $F(2, 80) = 3.81, p = .026, N_p^2 = .09$.

To follow up the significant interaction between crisp type and perceptual load condition, simple contrasts were carried out. As we were primarily interested in the effect of perceptual load on the salted – unsalted difference in intake, a one way ANCOVA was carried out with level of load as a fixed factor and salted – unsalted intake difference as a dependent variable, while controlling for restraint and sensitivity to reward (covariates which were previously shown to be related to intake). Restraint, $F(1, 85) = 6.80, p = .011, N_p^2 = .07$, and Sensitivity to reward, $F(1, 85) = 4.18, p = .044, N_p^2 = .05$, were again found to be significant covariates. After controlling for covariates, level of load significantly predicted the salted – unsalted intake difference, $F(1, 85) = 4.14, p = .019, N_p^2 = .09$. Simple contrasts showed that the salted – unsalted intake difference was significantly larger in the low perceptual load, ($M = 23.00, SE = 3.18$), $t(85) = 2.46, p = .016, d = .68$, and high perceptual load conditions, ($M = 22.29, SE = 3.50$), $t(85) = 2.53, p = .013, d = .62$, compared to the control group. There was no difference between low and high perceptual load conditions, ($M = 12.47, SE = 2.33$), $t(85) = .08, p = .938, d = .04$.

To check what the salted – unsalted differences were driven by, simple contrasts were carried out comparing level of perceptual load on intake of salted and unsalted crisps. There was no difference in intake of unsalted crisps between any of the contrasts: low perceptual load compared to control, $t(80) = .80, p = .427, d = .31$; high perceptual load compared to control, $t(80) = 1.28, p = .205, d = .29$; and low compared to high perceptual

load, $t(80) = .49$, $p = .627$, $d = .03$. Participants consumed significantly more salted crisps in both the low perceptual load compared to control contrast, $t(80) = 2.98$, $p = .004$, $d = .84$, and for the high perceptual load compared to control contrast, $t(80) = 3.28$, $p = .002$, $d = .81$. There was no difference in salted crisp intake in low compared to high perceptual load conditions, $t(80) = .34$, $p = .731$, $d = .01$.

We again converted raw intake scores to a percentage of total intake. The main effect of crisp type was significant, $F(1, 87) = 135.29$, $p < .001$, $N_p^2 = .61$. However, there was no effect of perceptual load, $F(2, 87) = 1.28$, $p = .284$, $N_p^2 = .03$. Lastly, the interaction between crisp type and load was not significant, $F(2, 87) = 1.28$, $p = .284$, $N_p^2 = .03$. Participants consumed more salted than unsalted crisps under all levels of perceptual load: low perceptual load (unsalted intake, $M = 32.48\%$, $SE = 2.34$; salted intake, $M = 67.52\%$, $SE = 2.34$); high perceptual load (unsalted intake, $M = 31.07$, $SE = 2.65$; salted intake, $M = 68.93$, $SE = 2.65$); and the control condition (unsalted intake, $M = 36.47$, $SE = 2.44$; salted intake, $M = 63.53$, $SE = 2.44$).

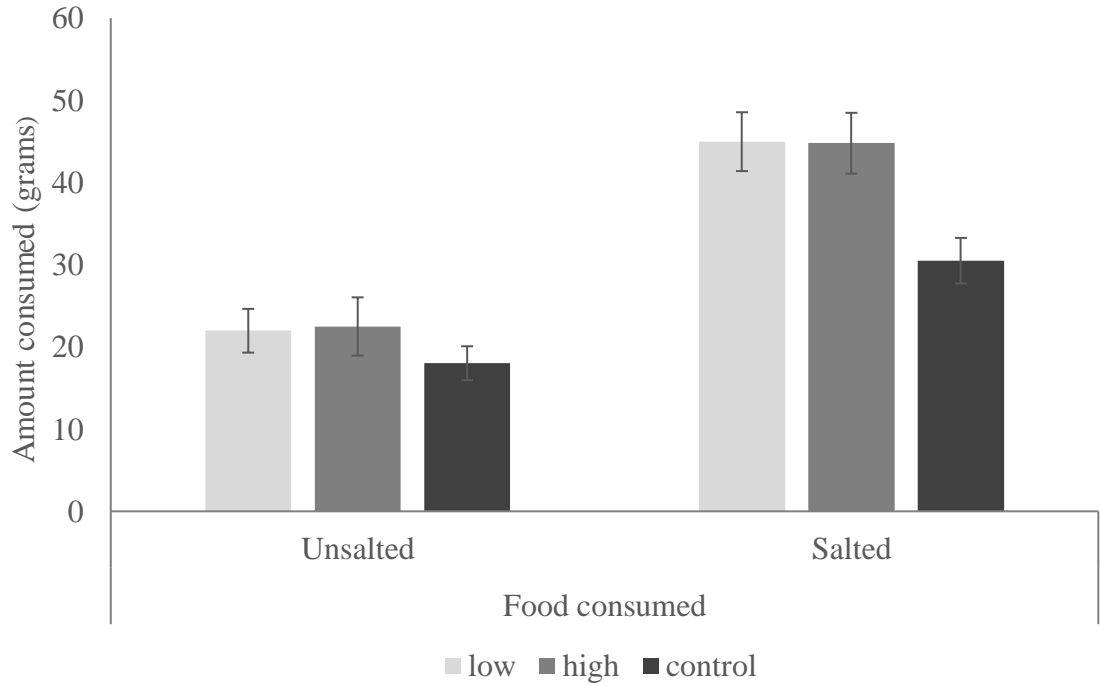


Figure 4: Amount of salted and unsalted crisps consumed under low and high perceptual load in Experiment 2.

Memory ratings. As in Experiment 1, we collected memory ratings of how pleasant and salty participants remembered the crisps being.

Pleasant ratings. There was a significant main effect of crisp type: participants rated salted crisps as more pleasant than unsalted crisps, $F(1, 87) = 95.21, p < .001, N_p^2 = .52$. There was also a significant effect of perceptual load, $F(2, 87) = 3.67, p = .029, N_p^2 = .08$. Pairwise comparisons revealed that pleasantness ratings were significantly higher in the high perceptual load condition compared to the control condition, $p = .025$. There was no difference between the low perceptual load and control condition, $p = .440$, or the low and high perceptual load conditions, $p = .652$. The crisp and load interaction was not significant, $F(1, 58) = 1.16, p = .319, N_p^2 = .03$.

Salted ratings. There was also a significant main effect of crisp type: from memory participants rated salted crisps as more salty than unsalted crisps, $F(1, 58) = 110.42, p < .001, N_p^2 = .56$. In contrast to the marginally significant effect found in Experiment 1, there was no effect of perceptual load on salty rating, $F(2, 87) = 1.39, p = .255, N_p^2 = .03$. The crisp and load interaction was also not significant, $F(2, 87) = 4.41, p = .015, N_p^2 = .09$.

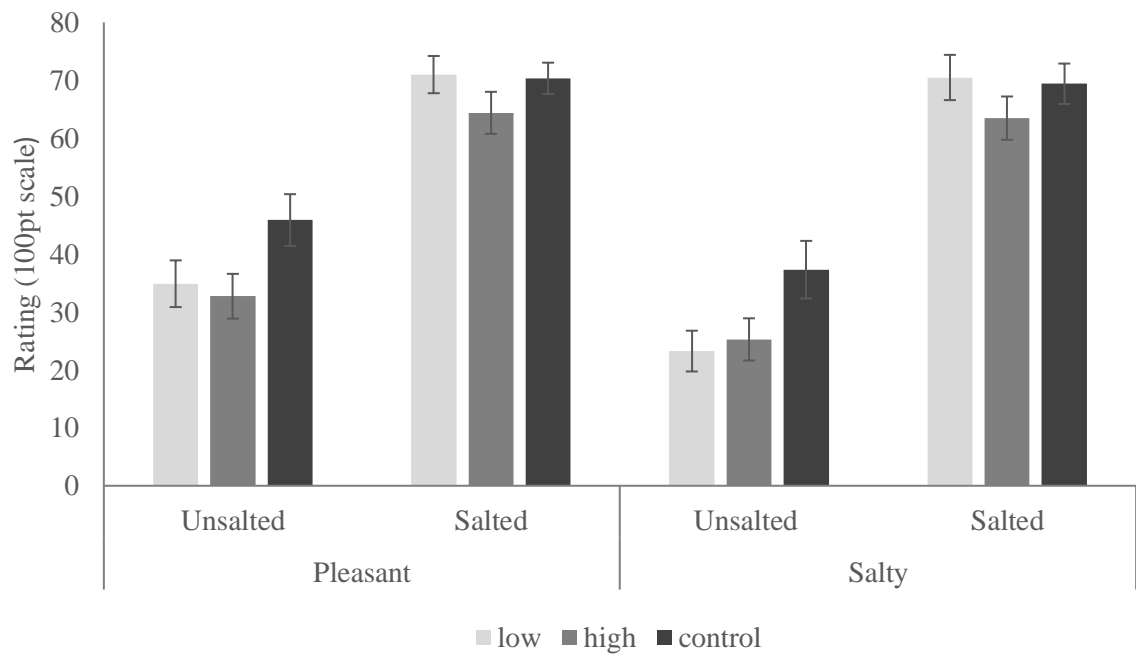


Figure 5: Pleasant and salty memory ratings of unsalted and salted crisps under low perceptual load, high perceptual load, and control conditions in Experiment 2.

Taste ratings.

Pleasant ratings. Like in Experiment 1, there was a significant main effect of crisp type. After tasting, participants rated salted crisps as more pleasant than unsalted crisps, $F(1, 87) = 171.55, p < .001, N_p^2 = .66$. There was no effect of perceptual load on pleasant

rating, $F(2, 87) = .19, p = .827, N_p^2 = .00$. The interaction between crisps and load was also non-significant, $F(1, 58) = .43, p = .65, N_p^2 = .01$.

Salted ratings. After tasting, participants rated salted crisps as significantly more salty than unsalted crisps, $F(1, 58) = 359.25, p < .001, N_p^2 = .81$. There was no effect of perceptual load on saltiness rating, $F(2, 87) = .04, p = .966, N_p^2 = .00$. The interaction between crisps and load was also non-significant, $F(2, 87) = .07, p = .929, N_p^2 = .002$.

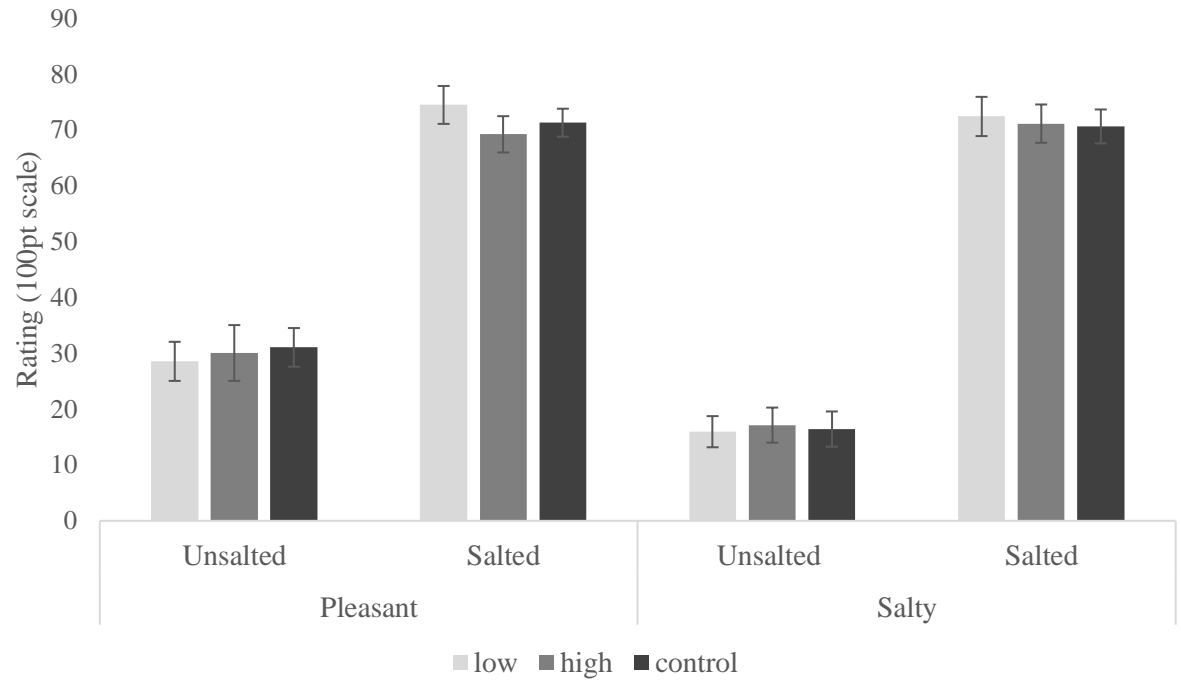


Figure 6: Pleasant and salty taste ratings of unsalted and salted crisps under low perceptual load, high perceptual load, and control condition in Experiment 2.

Sample characteristics. Table 3 shows the individual characteristics of the sample for Experiment 2, split by the condition that participants were allocated to. One way ANOVA's were carried out to check for group differences. Individuals did not significantly differ between load conditions on any of the individual difference traits measures displayed in Table 3, all $ps > .190$.

Table 3: Mean characteristics of the sample, across load conditions, for Experiment 2.

Standard errors are reported.

	Hunger	TFEQ_R	TFEQ_D	BIS11	SR	DEBQ_ E	BMI
Low load	51.00 (4.10)	8.1 (.76)	8.00 (.43)	18.77 (.87)	12.47 (.75)	3.38 (.09)	22.85 (.92)
High load	52.27 (4.03)	8.70 (.67)	6.77 (.54)	17.83 (.53)	12.07 (.85)	3.39 (.10)	24.34 (.64)
Control	47.20 (3.60)	7.23 (.69)	7.33 (.52)	16.97 (.63)	11.07 (.73)	3.37 (.10)	22.67 (.56)

Note: Hunger = Baseline self-reported hunger; TFEQ_R = Three factor eating questionnaire, restraint subscale; TFEQ_D = Three factor eating questionnaire, disinhibition subscale; BIS 11 = Baratt Impulsivity Questionnaire total score; SR = Sensitivity to punishment and reward Questionnaire, reward subscale; DEBQ_E = Dutch Eating Behaviour Questionnaire, external eating subscale, BMI = Body Mass Index.

Bayesian analyses

To fully interpret key non-significant results, we conducted Bayesian analyses on results important to our interpretation, calculated using Dienes (2008) online Bayes calculator. This was to establish the extent to which the data provided evidence for the null hypotheses. Using the benchmarks provided by Dienes (2014) a Bayes factor of less than a third is evidence for the null hypothesis, more than three is evidence for the alternative hypothesis and any value in between reflects insensitivity. A half normal distribution was used, as all predictions were directional.

Bayes factors were calculated for the non-significant effect of perceptual load (i.e., salted – unsalted difference under low compared to high perceptual load) for intake, memory and taste ratings in both Experiment 1 and 2. Priors for the effect were identified from Van der Wal & van Dillen (2013), who found that a distraction task reduced awareness of a salted – unsalted difference between crackers. Both Bayesian priors and data from the current experiment was converted to percentage data to account for measurement differences. For the effect of perceptual load on intake, a prior of 10% (intake change) was used. For the effect of perceptual load on sensory ratings, a prior of 12% (rated flavour awareness reduction) was used – this prior was used for both Bayesian tests ‘pleasant’ and ‘salty’ ratings, as priors for the exact equivalent ratings could not be identified.

In Experiment 1, all resulting Bayes factors (BF) were found to be insensitive: Intake BF = .93; Pleasant memory rating BF = 2.18; Salty memory rating BF = 1.55; Pleasant taste rating BF = .77; Salty taste rating BF = 2.03. Therefore, the Bayesian analyses performed do not provide strong evidence for the null hypotheses found in Experiment 1.

In Experiment 2, there was a marginally sensitive BF for the effect of perceptual load on intake, $BF = .45$, suggesting that Experiment 2 was sensitive to find this non-significant effect. All BF's for the low vs high perceptual load effect on sensory ratings were found to be insensitive: Pleasant memory rating $BF = .84$; Salty memory rating $BF = 1.31$; Pleasant taste rating $BF = 1.05$; Salty taste rating $BF = .68$.

For the sensory ratings, there were also non-significant differences between low/high perceptual load conditions and the control condition, and therefore, additional BF's were calculated. All BF's for the low vs control perceptual load effect on sensory ratings were found to be insensitive: Pleasant memory rating $BF = 2.27$; Salty memory rating $BF = 2.48$; Pleasant taste rating $BF = 1.02$; Salty taste rating $BF = .63$. Finally, for the high vs control perceptual load effect on sensory ratings, all BF's were again found to be insensitive: Pleasant memory rating $BF = 1.16$; Salty memory rating $BF = .98$; Pleasant taste rating $BF = .62$; Salty taste rating $BF = .51$. While several of these BF's are approaching the .33 threshold for sensitivity, they do not provide strong evidence for the null sensory ratings in Experiment 2.

It should be noted that the accuracy of Bayesian analyses is dependent upon the prior used (Dienes, 2014). As the effect of perceptual load on flavour awareness was a novel effect, an exact prior could not be established from the literature. Therefore, the BF's in this study have been calculated on the assumption that the distraction task used by Van der Wal & van Dillen (2013) had comparable effects to what could be expected from the perceptual load task. The priors used were more informative than using a default effect size, however, the calculated BF's should be considered in light of this limitation.

4.3.3. Discussion

Experiment 2 replicated our finding that perceptual load does not reduce flavour awareness. Participants consumed more of the palatable food under all levels of load. There was no difference between intake under low and high perceptual load. However, participants did consume more in the load conditions compared to the control condition, potentially demonstrating the typical inattentive eating effect previously shown in the literature. The salted-unsalted difference intended to reflect flavour awareness was more pronounced in the load conditions than in the control condition. Therefore, Experiment 2 did not provide evidence for the hypothesis that perceptual load would reduce flavour awareness. Similarly, perceptual load did not influence memory ratings of pleasantness and saltiness, suggesting that perceptual load has no effect on subsequent memory of flavour awareness.

4.4. General Discussion

Across three experiments, we found no evidence for our hypothesis that perceptual load would reduce flavour awareness. Under both low and high perceptual load, participants consumed more salted than unsalted crisps. They also rated salted crisps as more pleasant and more salty than unsalted crisps. The addition of a control condition in Experiment 2, which involved no manipulation of perceptual load, revealed that the salted – unsalted difference in intake was more pronounced in low and high perceptual load conditions compared to the control condition, providing further evidence against our hypothesis.

Previous research has implied that lack of flavour awareness could be a mechanism of inattentive (or ‘mindless’) eating (Braude & Stevenson, 2014). However, only one study we are aware of has directly tested whether a distraction task reduces awareness of flavour. Van der Wal & Van Dillen (2013) found ratings of flavour intensity were reduced and participants consumed more snack food when distracted. These results might at first appear to contradict our findings, however, they may instead highlight different aspects of flavour in eating behaviour. In an attempt to obtain a measure not reliant on self-reported ratings, we had no information about participant’s initial flavour perceptions, whereas Van der Wal & Van Dillen (2013) were able to test this. Therefore, it is unknown, but possible that initial flavour perception was also dampened by perceptual load in our experiments. What our findings do suggest, is that flavour awareness does not subsequently influence intake or sensory ratings taken after prolonged exposure and consumption of a snack-food. This has implications for research investigating the effect of distraction on disrupting sensory specific satiety (Braude & Stevenson, 2014; Brunstrom & Mitchell, 2006). We did not

incorporate sensory specific satiety in our design, but our results indicate that reduced flavour awareness is unlikely to be the mechanism underlying this effect.

One potential issue with our design was the novel application of load theory to create an ‘inattentive eating’ task. As the task had not been used before, it raises the question of whether the task can be applied to eating behaviour. For example, although high perceptual load is known to powerfully absorb attention (Lavie, 2005, 2010), the action of a hand movement to pick up crisps could have potentially allowed momentary lapses in attention. However, if this was the case then the lack of attention should have been reflected by a relationship between intake and poor task performance (as participants eating more food would have been making more hand movements). However, no relationships were found on either reaction time or accuracy measures on the perceptual load task and intake. Being able to confirm that participants were sufficiently engaged in the task throughout the entire testing period is an advantage of our task over usual inattentive eating paradigms (e.g., watching television). In addition, in Experiment 2 participants consumed more food (overall) in the control condition compared to both low and high perceptual load conditions. Therefore, our paradigm was able to detect a typical inattentive eating effect and therefore should have been able to find a load effect on flavour awareness.

There has been some suggestion that the working memory processing of taste and smell may be governed by separate sub-systems (Andrade & Donaldson, 2007; Baddeley, 2012), although evidence is tentative, and few studies have directly tested this assertion. If true, this could explain why the visual version of the perceptual load task did not modulate flavour processing (as presumably the task would not tax processing in the separate flavour sub-system). However, perceptual load can act cross-modally (Klemen, Büchel, & Rose,

2009). Although taste has not been investigated, it has been shown that perceptual load reduces detection of smells (Forster & Spence, 2018). Therefore, it appears unlikely that our results could be explained by an immunity of taste and smell sub-systems to the effect of perceptual load.

Eating imposes a special demand in that both taste and smell (in addition to visual, auditory and visual cues: see Spence, 2013 for discussion) are combined to create the experience of ‘flavour’. Research has demonstrated that multi-sensory stimuli are easier and faster to detect (Spence & Santangelo, 2009) and are represented as super-additive in the brain (Small et al., 2004). A full review of the role of perceptual load on multi-sensory processing is beyond the scope of this paper, but it has been shown to reduce interference from multi-sensory stimuli (Lunn, Sjoblom, Ward, Soto-Faraco, & Forster, 2019). Therefore, our results highlight one of the few exceptions to perceptual load theory and could help further establish the theoretical parameters. For this reason, the underlying cause of this exception deserves further study.

The primary implication of our results is that inattentive eating is not the result of reduced flavour awareness. Identifying the mechanism responsible is important given the link between obesity and eating while watching television (Boulos, Vikre, Oppenheimer, Chang, & Kanarek, 2012). Our results suggest advice to attend to food flavour to avoid over-eating may be unwarranted, as participants were aware of flavour even when their attention was absorbed in a perceptually demanding task. Interestingly, two recent multi-experiment attempts to reduce later snack consumption through ‘attentive eating’ found no effect on intake (Whitelock, Gaglione, Davies-Owen, & Robinson, 2019; Whitelock, Higgs, Brunstrom, Halford, & Robinson, 2018). Attentive eating manipulations tend to focus on

enhancing the sensory characteristics of the food, and the authors suggested that instructions emphasising the satiating effects of food or portion size may be more effective. Establishing the factors involved in inattentive eating allows for more specific and useful advice to be given. Given the potentially overwhelming amount of advice given to those who want to reduce their intake, making clearer recommendations is a key aim of research in this area (Buchanan & Sheffield, 2017).

In summary, we have shown across two experiments that perceptual load does not modulate flavour awareness in an inattentive eating paradigm. This suggests that awareness of flavour, despite being commonly assumed as a factor, does not contribute to inattentive (or ‘mindless’) eating behaviour. Instead, flavour may be a powerful sensory experience that supersedes even strong manipulations of attention. Our results are useful in ruling out reduced flavour awareness as the mechanism of inattentive eating and imply that future research should focus on alternative explanations.

4.5. Interim summary

The results of paper three raised the possibility that perceptual load theory could not be effectively applied to the study of eating behaviour, and therefore raised questions about the latter aspect of the proposed perceptual load theory framework: that availability of perceptual resources was important to process aspects of eating behaviour once consumption had commenced. This was an important aspect of the framework to establish as it determined the potential real-world recommendations that could be given. For example, if perceptual load only affected eating behaviour prior to consumption (i.e., attentional bias and intrusive thoughts), but had no effect on intake, then it might be useful to engage in perceptually demanding tasks as often as possible.

However, it might have been either that the lack of perceptual load on flavour awareness was an exception to the overall framework, or that the design made a potential effect of perceptual load difficult to observe. Therefore, in paper four, the effect of perceptual load was tested on a different aspect of eating behaviour: satiety. In addition, the design of paper four utilised an intra-oral infusion device (Tastebud: Vi, Arthur, & Obrist, 2018) to control for as many potential confounds as possible, such as pre-ingestive cues and the motor demand associated with picking up food. This allowed the effect of perceptual load to be tested more directly. Once again, due to the feasibility constraints of manipulating satiety and perceptual load within the same task, a between-subjects design was used in paper four. Key trait differences were included in analysis as covariates.

5. Paper four: Ingested but not perceived: response to satiety cues disrupted by perceptual load

Jenny Morris, Chi Ti Vi, Marianna Obrist, Sophie Forster, Martin R. Yeomans

Abstract

Selective attention research has shown that when perceptual demand is high, unattended sensory information is filtered out at early stages of processing. We investigated for the first time whether the sensory and nutrient cues associated with becoming full (satiety) would be filtered out in a similar manner. One-hundred and twenty participants consumed either a low-satiety (75kcal) or high-satiety (272kcal plus thicker texture) beverage, delivered via an intra-oral infusion device while participants simultaneously completed a task which was either low or high in perceptual demand. Among participants who performed the low perceptual load task, ingestion of the high-satiety beverage increased rated satiety and reduced consumption at a subsequent snack test. However, both effects were eliminated by the high perceptual load task. Therefore, the processing of satiety cues was dependent on the availability of attention, identifying a novel perceptual load mechanism of inattentive eating and supporting more recent cognitive models of appetite control.

5.1. Introduction

Satiation, referring to the process that causes cessation of intake, and satiety, the feeling of fullness after a meal that suppresses further intake, are key components of appetite control (Blundell & Tremblay, 1995). The satiety cascade has outlined a variety of processes involved in generating satiation and satiety, which have tended to be split into early cognitive and sensory influences, and later post-ingestive influences (Bellisle & Blundell, 2013; Blundell & Tremblay, 1995). More recently, stronger cognitive models of eating behaviour have suggested that satiety is partly cognitively constructed and dependent upon memory (Higgs et al., 2017). These models are supported by considerable evidence that reducing memory for a consumed food by interfering with attention at the time of initial consumption (e.g., by watching television or playing games) increases subsequent consumption (Higgs, 2015; Higgs & Woodward, 2009; Mittal, Stevenson, Oaten, & Miller, 2011; Oldham-Cooper, Hardman, Nicoll, Rogers, & Brunstrom, 2010; Robinson et al., 2013).

Several potential mechanisms have been suggested to explain the role of attention and memory in eating behaviour. For example, manipulations of attention have been argued to influence subsequent intake via changes in meal memory (Higgs & Spetter, 2018; Robinson, Kersbergen, & Higgs, 2014). In support of this claim, when food is consumed while distracted, subsequent memory ratings for vividness of the food and accuracy of which food items had been consumed were reduced (Higgs, 2015). Another potential explanation is that memory for recently consumed food increases attention to physiological appetite signals (e.g., hunger and fullness) and therefore allows the individual to adjust subsequent intake accordingly (Higgs, 2005).

However, in both potential explanations the attentional mechanism is implied—it is unknown to what extent the subsequent memory effects are due to lack of attention. In addition, other explanations such as mood cannot be ruled out, as paradigms most commonly compare television (which is known to influence intake via changes in mood, Yeomans & Coughlan, 2009) to a no task control condition (which could induce boredom). One study varied engagement with a computer task by offering a financial reward to the highest performing participant of the week (Higgs, Dolmans, Humphreys, & Rutters, 2015) and found that recall for the serial order of lunch items and memory vividness of the lunch was reduced and subsequent consumption was greater in the high compared to low engagement condition. These results are consistent with an attentional explanation (that greater attention was paid to the distraction task when a reward was offered), however, there is no direct evidence that this is the case.

Furthermore, part of the memory effect on satiety may be explained by factors that act only on post-ingestive aspects of satiety, rather than the processing of satiety information at the time of initial consumption. Brunstrom et al. (2012) used a refilling soup bowl paradigm to manipulate actual intake (300ml vs 500ml) without participant awareness (aware participants were removed) and perceived intake (300ml vs 500ml). Actual food consumption guided appetite ratings immediately after consumption (e.g., the larger portion reduced hunger), suggesting that nutrient-based satiety was controlling appetite despite lack of awareness of amount consumed. Memory for the perceived amount eaten only influenced satiety two hours after the initial consumption (the perceived larger portion reduced hunger and actual intake had no effect). Therefore, memory for amount consumed had a powerful effect on appetite, but only once nutrient-based satiety effects had worn off.

The current research will utilise Load Theory, a key theory from the selective attention literature, to more directly test the role of attention in satiety. Load Theory suggests that the extent to which task-irrelevant stimuli are processed is limited by the availability of attention, which is determined by whether the primary task leaves adequate spare perceptual capacity (Lavie, 2005, 2010). Increasing the perceptual demand in a task (e.g., searching for a friend in a crowded vs. an empty restaurant) exhausts perceptual capacity, resulting in irrelevant stimuli not receiving attentional processing. Crucially, this is a passive process carried out automatically by the perceptual system at an early stage of selection.

A large body of evidence has demonstrated the powerful effects of perceptual load in reducing task-irrelevant processing across a range of paradigms (for reviews see, Lavie, 2005, 2010; Murphy, Groeger, & Greene, 2016). The most widely used manipulation has been the visual search task, where participants search for a target letter among five small o's (low perceptual load) or five non-target letters (high perceptual load) while ignoring irrelevant stimuli (e.g., Forster & Lavie, 2008; Lavie, 1995). Typically, irrelevant stimuli cause distractor interference (measured by slower reaction times to the central task) under low perceptual load, but this is reduced or eliminated under high perceptual load. Importantly, this task isolates the effect of perceptual demand on attention while keeping other types of load constant (e.g., cognitive load, which has been shown to have the opposite effect on attentional processing, Lavie, Hirst, de Fockert, & Viding, 2004).

Further evidence has demonstrated that when attentional capacity is exhausted by a perceptually demanding task, processing of task-irrelevant stimuli is powerfully reduced from the earliest stages of perception (e.g., V1 for visual stimuli) onwards, with the result that higher level processing such as encoding into memory, and awareness, is substantially

diminished and may even fail to occur (for review see, Lavie, 2005; 2010). Although such effects are most well-established with respect to visual stimuli, they have more recently been shown to extend across the senses to smell, hearing and touch (Dalton, Lavie, & Spence, 2009; Forster & Spence, 2018; Macdonald & Lavie, 2011).

In a recent paper (Morris, Yeomans & Forster, 2020), we proposed that a Perceptual Load Theory framework could accommodate multiple aspects of eating behaviour, from the response to external food cues, to the experience of appetitive thoughts, to distracted eating. Our initial work in support of this proposal has shown that high perceptual load in this task eliminates distraction by, and reduces memory for, external, highly palatable food stimuli (Morris, Yeomans & Forster, 2020) and reduces internal appetitive-related thoughts (Morris, Ngai, Yeomans & Forster, 2020). Potentially also consistent with this idea, research from the eating behaviour literature has suggested that both taste responsiveness (Duif et al., 2020a) and goal directed behaviour in order to obtain food (Duif et al., 2020b) were disrupted by a perceptually demanding rapid serial visual presentation task. The goal of this study was hence to further test the applicability of Load Theory to the eating behaviour literature. This was examined by testing whether occupying attention during and immediately after ingestion might similarly disrupt the brain's processing of satiety signals, with the result of eliminating the effect of satiety on later appetite.

Growing evidence that eating while distracted by real-world tasks such as television can affect subsequent intake (Robinson et al., 2013) is initially consistent with this idea, although such findings could also reflect factors such as mood or memory for prior consumption. The current study set out to test a stronger cognitive model, using controlled manipulations of both attention and satiety, which suggests the generation of satiety is dependent on the consumer being able to attend to the satiety signals generated during and

after ingestion. This model has particular relevance to intake of snack foods and beverages, where satiety signals may be relatively small and transient, and which have been implicated in overconsumption and a risk of obesity (e.g., Bellisle, 2014, although see Keast, Nicklas & O'Neil, 2010).

5.2. Methods

5.2.1. Participants

One hundred and twenty female participants aged between 18 – 35 years ($M = 20.58$, $SD = 2.53$) were recruited to take part in a study advertised as ‘The effect of a smoothie drink on cognition’. This cover story was selected to reduce potential demand effects, in line with recommendations on the conduct of appetite studies with human participants (Robinson, Kersbergen, Brunstrom, & Field, 2014). The sample was restricted to female participants only because of the difficulty recruiting an equal number of men and women from a predominantly female cohort of students, and therefore we wanted to avoid potential gender-related intake differences in an uneven sample obscuring experimental effects (Mittal, Stevenson, Oaten, & Miller, 2011). Participants had normal or corrected to normal (e.g., with glasses) vision and were native English speakers or as fluent at both speaking and reading English as a native speaker. Participants were primarily University of Sussex students who received course credits or a nine-pound financial compensation.

The current experiment was closely based on previous research from the Sussex Ingestive Behaviour laboratory, which investigated the effect of energy content and sensory properties in a beverage on satiety (McCrickerd et al., 2014). We used G*Power to calculate our sample size based on effect sizes obtained by McCrickerd et al., (2014), which used the same preload manipulation as the current experiment, and Yeomans, McCrickerd, Brunstrom & Chambers (2014), which used the same between subjects design as the current experiment. Based on effect sizes of $d = .72$ (McCrickerd et al., 2014) and $d = .65$ (Yeomans et al., 2014) for the effect of a preload on appetite ratings, G*Power indicated that a sample size of 25 and 30 would be needed in each condition, respectively. Likewise, to detect the effects of the difference in preload energy on intake, effect sizes of d

= .67 (McCrickerd et al., 2014) and $d = .87$ (Yeomans et al., 2014) indicated a sample size of 29 and 18 in each condition would be needed, again reported respectively. To ensure we could detect effects of preload on both appetite ratings and snack intake, we therefore used a sample of 30 participants in each condition.

The study was approved by the University of Sussex Sciences & Technology Cross-Schools Research Ethics Committee. All participants provided informed consent.

5.2.2. Design

A between subjects 2x2 design was used to assess the development of satiety (measured by changes in appetite ratings and consumption at a snack intake test) in response to a “preload” (here a beverage: low energy thin texture or high energy thick texture) consumed either while participants performed a low or high perceptual load task.

5.2.3. Test Beverage and Foods

All participants consumed a standard breakfast in the Sussex Ingestive Behaviour Laboratory, later followed by the test drink and an intake test disguised as a taste test. They received a 500 ml bottle of spring water (Sainsbury’s, UK) to drink in-between breakfast and the main test session. For breakfast, participants were given Crunchy Nut Cornflakes (Kelloggs, UK: 60 g), semi-skimmed milk (Sainsbury’s, UK: 160 g) and orange juice (Sainsbury’s, UK: 200 g), which provided 440 kcal in total.

The recipe for the two test drinks was developed in a previous study (McCrickerd et al., 2014) using commercially available ingredients. The two test drinks which had the largest contrasting effect on appetite in the previous study (where attention was not manipulated) were used for the current study: a low energy thin texture drink (LE) and a high energy thick texture drink (HE). The thinner low energy drink generates a weak effect on satiety and the slightly thicker textured higher energy drink reliably generates stronger

satiety. Previous research has shown that experienced satiety depends upon the combination of congruent sensory and physiological cues (Chambers, Ells & Yeomans, 2013; Yeomans & Chambers, 2011; Camps, Mars, De Graaf, & Smeets, 2016; McCrickerd, Tay, Tang & Forde, 2020), and therefore the thin LE vs. thick HE comparison maximised the potential difference in satiety response.

The drinks were prepared as a 297 g portion, each containing fresh mango, peach and papaya fruit juice (LE and HE = 100 g; Tropicana Products, Inc.), 0.1% fat fromage frais (LE = 55 g, HE = 30 g; Sainsbury's UK), water (LE = 130 g, HE = 100 g) and peach diluting drink (LE and HE = 11 g; 'Robinsons' from Britvic, UK). The HE version of the drink also contained maltodextrin (Cargill, UK: 55 g) and as a result one portion of the HE drink contained 272 kcal while the LE drink contained 75 kcal. Tara gum (Kalys Gastronomie, FR) was added to the HE drink to increase its viscosity (thin LE = 0.2 g; thick HE = 1 g). Aspartame was used in the LE drink to match sweetness to the HE drink (Ajinomoto, Japan: 0.03 g).

Participants also consumed savoury snack foods in a disguised taste test. They received ready salted crisps (Walkers, UK: 40 g), cool tortilla chips (Morrisons, UK: 40 g) and mini poppadums (Morrisons, UK: 30 g). The smaller amount of mini poppadums was to account for their larger volume, so that participants were presented with a visually similar amount of each snack.

5.2.4. Perceptual load task

All stimuli were presented using Eprime 2.0 (Schneider, Eschman, & Zuccolotto, 2002) on a 13.5-inch computer screen. The experiment was presented on a grey background and all letter stimuli were black.

We adapted the task from Forster and Spence (2018). Participants completed either six low or high perceptual load blocks of a visual search task. Each trial started with a central fixation cross displayed for 500 ms, immediately followed by the letter stimuli, the letters appeared for 100 ms but the response window was 2000 ms. The next trial began after the 2000 ms response window had finished regardless of when a response was given. This was to ensure that participants completing the low load version of the task (where responses are typically quicker) spent the same time carrying out the task as those completing the high load version.

Example stimulus displays are shown in Figure 1. Each stimulus display comprised a circle of 6 letters, participants searched for a target letter within the circle, either an X or an N, and responded with the corresponding key. Perceptual load was manipulated by varying the set-size of the letter circle. The letter circle had a 2.4 degree radius (each letter subtending 1.2 by 1 degree). In the high-load condition, the non-target letters in the circle (selected at random from H, K, M, Z, W, V) were placed randomly around the circle. In the low load the small 0's were 0.19 degrees.

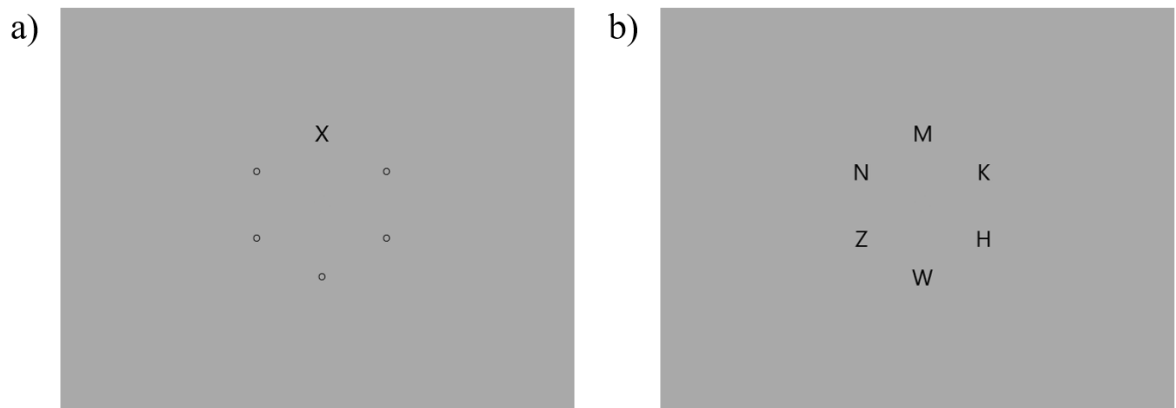


Figure 1. Example stimulus displays showing: (a) low load trial, (b) high load trial.

5.2.5. Procedure

Figure 2 provides a summary of the test day procedure. Participants arrived for breakfast in the laboratory between 8:15 and 10 am having consumed nothing except water from 23:00pm the evening before. Participants could then leave the laboratory for one hour, then returned for their main test session. They were instructed to consume only water in this time and were given a 500 ml bottle of water to take with them. Upon their return to the laboratory, participants were seated in a testing cubicle where they completed a set of visual analogue ratings run on Eprime 2.0.

Experienced satiety and mood were measured using a 0-100 visual analogue scale (VAS). A composite measure of experienced satiety was created from four ratings: hunger, fullness, desire to eat and 'how much' could participants eat. There were five mood ratings: calm, tired, headachy, clearheaded and energetic. Each VAS scale was presented as a 100 mm horizontal line on the computer screen. Each question appeared above the line with a lower end anchor of 'Not at all' and an upper end anchor of 'Extremely'. Participants dragged the cursor from the midpoint of the scale to show their current state. All VAS ratings were presented in a randomised order.

Next participants completed three slowed down example trials of the perceptual load task and twenty-four normal speed practice trials for the level of load in their condition.

The preload beverage was delivered via an intra-oral infusion device (TasteBud: Vi, Arthur, & Obrist, 2018), which allowed us to control the time of delivery, remove as many pre-ingestive cues as possible (e.g., visual cues, motor actions associated with ingestion) and ensure participants consumed the preload while fully distracted by the perceptual load task. The Tastebud delivery system used a peristaltic pump to push the beverage through a

plastic tube and into the participant's mouth – similar delivery systems have been used in previous research (e.g., Zijlstra et al., 2008, 2009; Bolhuis et al., 2011). The tube was attached to a disposable plastic straw that participants held in their mouth. The liquid was delivered at a slow constant rate (37g per minute) with no need for participants to use their hands to consume the liquid.

Once participants pressed a key to start the task the delivery of the beverage began automatically. The delivery of the beverage lasted nine minutes. The perceptual load task continued for this length of time. After delivery of the beverage had finished participants were instructed to put the straw to the side and continue with the perceptual load task.

Participants then completed six blocks of the perceptual load task during the inter-meal interval, which lasted for a total of 32.5 minutes (intervals of 30 – 120 minutes have been previously suggested to maximise potential energy compensation, Almiron-Roig et al., 2013). Each block continued for five minutes. After each block participants were given a thirty-second break where they were asked to focus on the strategies they had used in the previous block, and how they could improve in the next block.

Upon completing the perceptual load task, participants repeated the visual analogue ratings measuring hunger and mood.

Next, participants were given a disguised snack intake test, intended to assess satiety (via calorie consumption of the snacks). The experimenter presented participants with a tray of savoury snacks (three varieties of crisps) in bowls labelled with a three-digit number. Participants were instructed they had five minutes to taste the snacks and complete the ratings that appeared on the screen. They were told they could eat as much of the snack foods as they wanted, as they would be thrown away after. Participants made ratings on

how pleasant, salty and sweet they thought the snacks were (these ratings received no further analysis).

Participants completed a set of questionnaires measuring individual difference characteristics related to eating behaviour. Using a between-groups design raised the risk that difference between conditions could be affected by group differences in body-size or in traits known to affect satiety responses. For example, dietary restraint and disinhibition have both been specifically linked to an altered response (counter-regulation) to preload consumption (Westenhoefer, Broeckmann, Münch, & Pudel, 1994). In addition, both over-reliance on external cues (Ogden & Wardle, 1990) and sensitivity to reward have been linked to over-eating (Franken & Muris, 2005). Therefore, we collected individual difference data to ensure each experimental group consisted of similar samples, which have been reported in Table S1. The four groups did not differ on any individual difference characteristics related to eating behaviour, all $ps > .200$.

After the questionnaires, participants rated the smoothie beverages on how 'creamy', 'sweet' and 'pleasant' and 'filling' they remembered them being. Finally, the researcher measured the participant's height and weight at the end of the experiment using a stadiometer with an integrated height measure, before thanking and debriefing them.

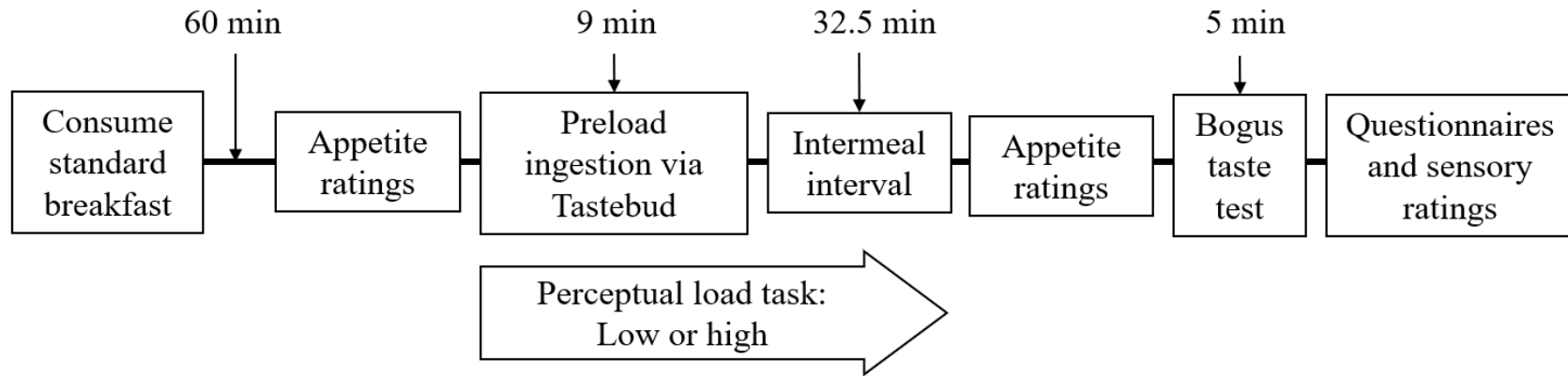


Figure 2. Schematic summary of the test day procedure (note that the preload ingestion via Tastebud took nine minutes in total – split into eight minutes for the preload delivery and a further one minute where the perceptual load task continued, to avoid an abrupt end of preload delivery).

5.2.6. Questionnaire measures

5.2.6.1. Three Factor Eating Questionnaire (Stunkard & Messick, 1985). The 51 item TFEQ is divided into three factors: restraint, disinhibition and hunger.

5.2.6.2. Dutch Eating Behaviour Questionnaire (van Strien, Frijters, Bergers, & Defares, 1986). Only the 10 item external eating subscale of the DEBQ was used in this experiment.

5.2.6.3. Sensitivity to punishment and reward Questionnaire (Torrubia, Ávila, Moltó, & Caseras, 2001). This 48-item questionnaire comprises two subscales. Sensitivity to reward which reflects behavioural activation, and the sensitivity to punishment which reflects behavioural inhibition.

5.2.7. Data Analysis

Firstly, manipulation checks were carried out to ensure the perceptual load task had the intended effect. 2 x 2 between subjects ANOVA's were carried out using the factors of perceptual load (low, high) and preload (LE, HE) on reaction time and accuracy data. The same factors were used in a 2 x 2 ANCOVA on change in mood ratings (post task mood rating – baseline mood rating), while controlling for the equivalent baseline mood rating. The following mood ratings were evaluated: calm, clearheaded, energetic, headache, tired.

The key research questions were regarding the impact of perceptual load on the typical preload effect expected in this design. On intake, a 2 x 2 ANCOVA was performed with the factors of perceptual load (low, high) and preload (LE, HE). To identify meaningful individual difference covariates, an exploratory ANCOVA was first carried out with all potential individual difference variables (restraint, disinhibition, sensitivity to reward, external eating and BMI) – this was done to avoid the loss of power associated with including numerous non-significant covariates in the model (Kahan, Jairath, Dore &

Morris, 2014). Significant covariates were included in all subsequent analyses. To investigate significant interactions between perceptual load and preload, follow up ANCOVA's testing the effect of preload on intake were performed under each level of perceptual load.

The same analysis process was carried out on change in experienced satiety data (post task satiety – baseline satiety). However, baseline satiety was included as an additional covariate (as suggested by Blundell et al., 2010).

Unadjusted means and models (without individual difference covariates) for the effect of perceptual load and preload on intake (Table S2 and Figure S1) and experienced satiety (Table S3 and Figure S2) have been reported in supplementary materials. Adjusting for covariates did not change the interpretation of any of our results.

As we expected to find non-significant effects of preload under high perceptual load, Bayes factors were calculated for these effects on intake and experienced satiety. Using the benchmarks provided by Dienes (2014) a Bayes factor of less than a third is evidence for the null hypothesis, more than three is evidence for the alternative hypothesis and any value in between reflects insensitivity. A half normal distribution was used, as all predictions were directional.

Finally, we calculated 2 x 2 ANOVA's (with the factors of perceptual load and preload) to test for group differences on sensory ratings collected after the experiment (pleasant, filling, sweet and creamy).

5.3. Results

All traditional analyses were conducted using IBM SPSS Statistics 24. Dienes (2008) online calculator was used to calculate Bayes factors for key non-significant results important to our interpretation.

5.3.1. Manipulation check

Only trials to which a correct response was made were included in reaction time analyses. All reaction times are reported in milliseconds. Slower reaction times (low perceptual load: $M = 513$, $SE = 10$; high perceptual load: $M = 751$, $SE = 15$), $F(1, 116) = 178.99$, $p < .001$, $N_p^2 = .61$, and lower accuracy rate, (low perceptual load: $M = .94$, $SE = .00$; high perceptual load: $M = .84$, $SE = .01$) $F(1, 116) = 60.15$, $p < .001$, $N_p^2 = .34$, under high compared to low perceptual load confirmed the expected increase in task difficulty. No other task performance effects were significant, all $ps > .531$.

Mood ratings were collected before and after the perceptual load task. The change in mood ratings (post task rating-baseline rating) are reported in Table 1. Due to outliers, headache data were removed for two participants. Change in mood ratings did not differ significantly based on perceptual load condition, all $ps > .256$. No other effects (the effects of preload and its interaction with perceptual load) were significant, all $ps > .125$.

Table 1

Change in mood (post task rating-baseline rating) in low and high perceptual load conditions (SE in parentheses). Data are estimated marginal means.

	Low perceptual load	High perceptual load
Calm	-5.58 (3.01)	-3.16 (3.01)
Clearheaded	-19.57 (2.73)	-17.07 (2.73)
Energetic	-22.69 (2.82)	-18.10 (2.82)
Headache	20.21 (3.50)	16.72 (3.50)
Tired	20.54 (3.22)	21.64 (3.22)

5.3.2. Effect of perceptual load on snack intake

Intake is presented in Figure 3. A between-subjects analysis of covariance (ANCOVA) was carried out, testing the effect of preload (LE, HE) and level of perceptual load (low, high) on crisp intake (calories). Exploratory analysis identified that the following covariates were significantly related to intake and therefore they were included in the main ANCOVA: sensitivity to reward, $p = .042$, and DEBQ external eating, $p = .008$. There were no other significant effects of covariates, all $ps > .482$.

There was a significant effect of sensitivity to reward, $F(1, 114) = 4.44$, $p = .037$, $N_p^2 = .04$, and DEBQ external eating, $F(1, 114) = 10.61$, $p = .001$, $N_p^2 = .09$, on intake. After controlling for the selected covariates, the ANCOVA showed that intake was significantly higher overall after consumption of the LE compared to the HE preload, $F(1, 114) = 9.44$, $p = .003$, $N_p^2 = .08$. Perceptual load had no overall effect on intake, $F(1, 114) = .08$, $p = .782$, $N_p^2 = .00$. Crucially, there was a significant interaction between preload and perceptual load, $F(1, 114) = 13.78$, $p < .001$, $N_p^2 = .11$.

To follow up the significant interaction between preload and perceptual load, one way ANCOVA's were carried out under each level of perceptual load, while controlling for DEBQ external eating and sensitivity to reward. The DEBQ external eating subscale was significantly related to intake under both low, $F(1, 56) = 6.89, p = .011, N_p^2 = .11$, and high perceptual load conditions, $F(1, 56) = 3.94, p = .052, N_p^2 = .07$. There was no significant effect of sensitivity to reward, all $ps > .094$. After controlling for covariates, there was a significant effect of preload under low perceptual load: participants who consumed the HE preload consumed 45% fewer crisps than participants who consumed the LE preload, $F(1, 56) = 25.85, p < .001, N_p^2 = .32$, confirming a satiety response. Critically, there was no equivalent difference in intake under high perceptual load, $F(1, 56) = .19, p = .665, N_p^2 = .00$, with near identical intake after LE and HE versions.

In addition, a Bayes factor was calculated for the non-significant effect of preload on subsequent intake under high perceptual load, using a prior of 60 (calories) obtained from McCrickerd et al, (2014). The resulting Bayes factor was .20, suggesting that the lack of satiety response under high perceptual load was a sensitive non-significant result. Therefore, participants showed no evidence of reduced intake in response to the HE compared to LE preload when engaged in the high perceptual load task, showing for the first time that inattention can mask responses to satiety cues.

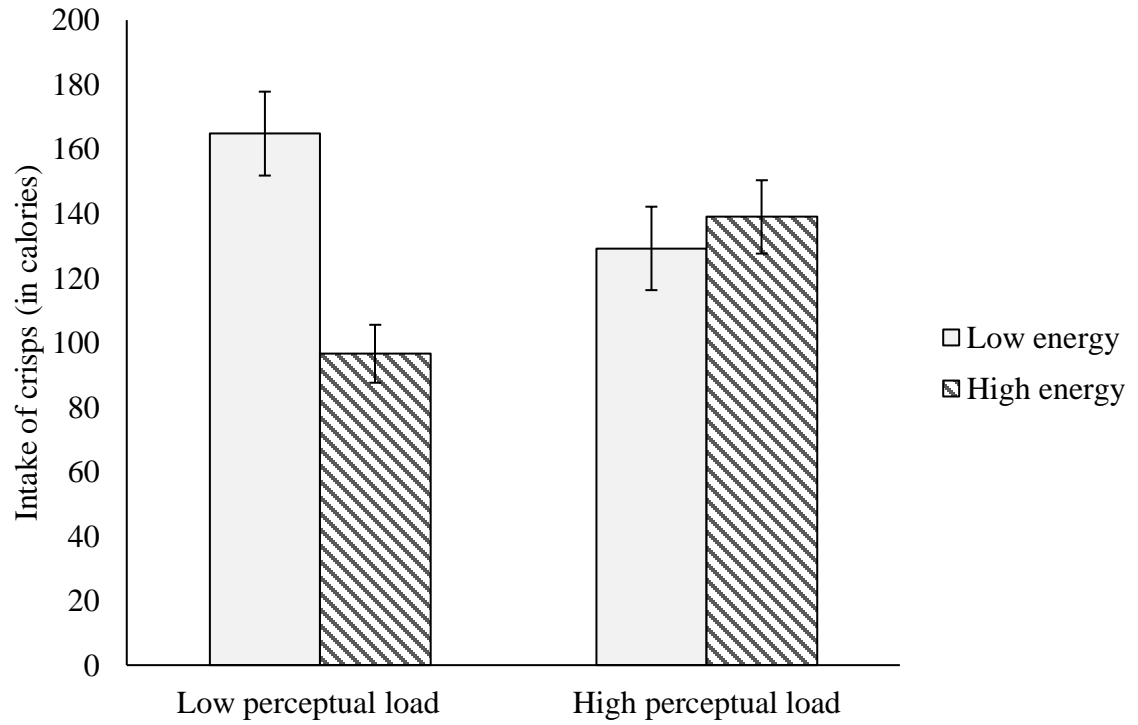


Figure 3. Mean calorie intake (\pm SEM) of crisps after consumption of LE or HE preload under low or high perceptual load.

5.3.3. Effect of perceptual load on experienced satiety

To test effects on the experience of satiety, participants completed visual analogue ratings of hunger, fullness, desire to eat and the amount they thought they could eat. There were no group differences on any of these ratings at baseline (at the start of the experiment), all $ps > .393$. We calculated change in satiety by subtracting baseline from post-task ratings and, as in previous studies (Deighton, Karra, Batterham, & Stensel, 2013; Harrold, Breslin, Walsh, Halford, & Pelkman, 2014; Perrigue, Drewnowski, Wang, & Neuhouser, 2016), combined these ratings into a single overall satiety index using the formula $((hunger + amount + desire\ to\ eat) - (fullness))/4$. These satiety index data were contrasted using a 2 x 2 ANCOVA with preload and perceptual load, while controlling for the baseline satiety index score and DEBQ external eating (which was identified as a marginally significant covariate in exploratory analyses, $p = .057$). Satiety index data are presented in Figure 4.

There was a significant effect of baseline satiety, $F(1, 114) = 19.36, p < .001, N_p^2 = .15$, and a marginally significant effect of DEBQ external eating on experienced satiety, $F(1, 114) = 3.32, p = .071, N_p^2 = .03$. There was no overall statistically significant effect of preload, $F(1, 114) = .76, p = .387, N_p^2 = .01$, or perceptual load, $F(1, 114) = .29, p = .590, N_p^2 = .01$. However, there was a significant interaction, $F(1, 114) = 7.94, p = .006, N_p^2 = .07$.

To follow up the significant interaction between preload and perceptual load, one way ANCOVA's were carried out under each level of perceptual load, while controlling for Baseline satiety and DEBQ external eating. Baseline satiety was significantly related to change in satiety under both low, $F(1,56) = 7.07, p = .010, N_p^2 = .11$, and high perceptual

load conditions, $F(1,56) = 12.37$, $p = .001$, $N_p^2 = .18$. There was no effect of DEBQ external eating, all $ps > .174$. After controlling for covariates, under low perceptual load, there was a greater reduction in experienced satiety from participants who consumed the HE compared to the LE drink, $F(1, 56) = 6.89$, $p = .011$, $N_p^2 = .11$. Again, there were no significant difference under high perceptual load, $F(1,56) = 1.73$, $p = .194$, $N_p^2 = .03$. Thus, changes in snack intake were mirrored by no evidence of any change in experienced satiety after the HE preload under high perceptual load.

Finally, a Bayes factor was calculated for the non-significant effect of preload on experienced satiety, using a prior of 3.54 (change in satiety index) obtained from previous unpublished research in the Sussex Ingestive Behaviour Laboratory. The resulting Bayes factor was .40, narrowly missing the .33 threshold for sensitivity.

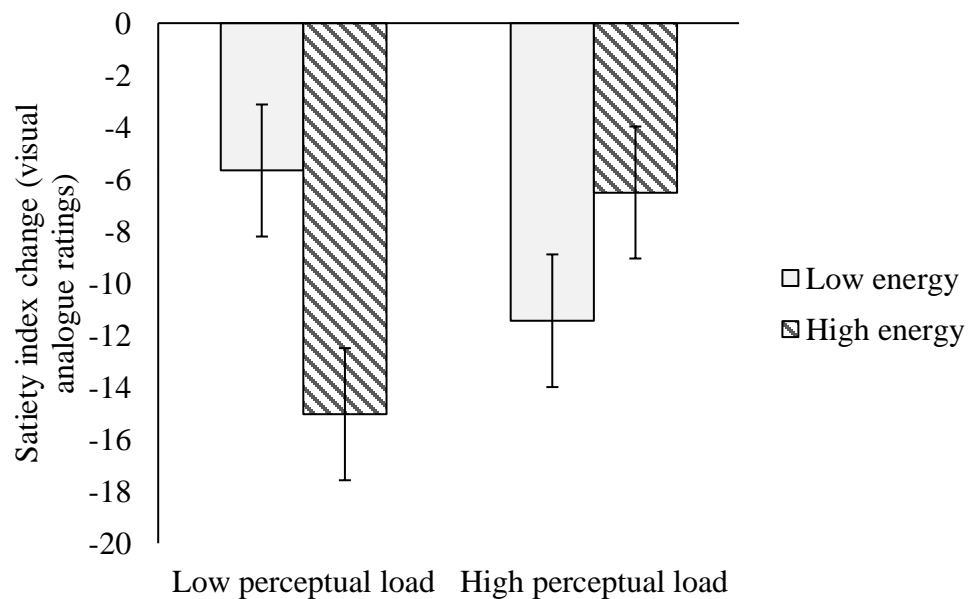


Figure 4. Overall satiety index change after consumption of LE or HE preload under low or high perceptual load. A larger negative score reflects a greater increase in experienced satiety.

5.3.4. Effect of perceptual load on sensory memory ratings

In addition, we collected sensory memory ratings of the smoothie drinks at the end of the experiment, which are displayed in Table 2. Participants rated the LE and HE drinks to be similar in how pleasant and sweet they remembered it being, all $ps > .142$. The HE preload was rated as significantly creamier than the LE preload (this was intentional in our design), $F(1, 116) = 12.23, p = .001, N_p^2 = .10$. However, unexpectedly participants who consumed the preload under high perceptual load rated it as significantly creamier than participants who consumed it under low perceptual load, $F(1, 116) = 6.89, p = .010, N_p^2 = .06$. There was a non-significant interaction between preload type and perceptual load, $F(1, 116) = .24, p = .626, N_p^2 = .00$. Crucially, the lack of interaction between preload type and perceptual load on all three sensory memory ratings reflects that there was no evidence of an effect of perceptual load on memory for preload sensory characteristics.

We also asked participants how “filling” they remembered each preload to be, and this neither differed between preloads, $F(1, 116) = .99, p = .322, N_p^2 = .01$, or perceptual load conditions, $F(1, 116) = .06, p = .802, N_p^2 = .00$. There was also no preload x perceptual load interaction, $F(1, 116) = .19, p = .663, N_p^2 = .00$.

Table 2

Sensory memory ratings (mean and standard error) between experimental conditions.

	Low perceptual load		High perceptual load	
	Low energy	High energy	Low energy	High energy
	preload	preload	preload	preload
Pleasant	66.33 (4.07)	60.13 (4.81)	57.30 (2.94)	62.93 (3.97)
Sweet	65.37 (2.33)	71.40 (2.61)	67.77 (2.55)	66.77 (3.62)
Creamy	39.17 (4.09)	54.40 (3.92)	51.07 (3.20)	62.57 (4.02)

5.4. Discussion

Together, the results show that satiety-based control over appetite can be disrupted when attention is absorbed in a perceptually demanding task. When attention was available under low perceptual load, participants consuming the HE thick preload ate 45% fewer crisps at a subsequent snack test and reported more than double the level of experienced satiety than those who consumed the LE thin preload (note that while participants did not fully adjust their intake for the energy difference between preloads, the size of the observed effect is similar to previous research, e.g., Almiron-Roig et al., 2013; McCrickerd et al., 2014). Neither of these effects were observed when attention was occupied by a perceptual load task during consumption, suggesting that attention is required for the brain to be aware of the sensory and subtle nutrient cues generated in the gut by ingestion of the two preload drinks. Importantly, these effects were observed in the absence of any load effect on mood or memory ratings of how filling, pleasant or sweet the preload beverage was. The thick texture beverage was rated as creamier than the thin texture beverage under both low and high perceptual load, suggesting that perceptual load did not reduce memory for that feature of the drink preloads.

Our results provide the first evidence that Load Theory of attention can be successfully applied to study ingestive behaviour. Furthermore, even when a strong effect of satiety was expected in response to a thick texture, high energy beverage, perceptual load significantly disrupted the satiety response. As has been pointed out, a reliable satiety response is dependent on the combination of sensory and physiological cues (Chambers, Ells & Yeomans, 2013; Yeomans & Chambers, 2011; Camps, Mars, De Graaf, & Smeets, 2016; McCrickerd, Tay, Tang & Forde, 2020), and therefore while we controlled for a variety of pre-ingestive cues in our design (e.g., visual cues and motor actions), the

beverages differed on the key sensory characteristic of texture. As this was the first application of Load Theory in this area, it was most important to test whether perceptual load would modulate a strong satiety response. The pattern of observed results regarding satiety response suggest that perceptual load modulated the effect of both sensory and physiological cues, as satiety was completely eliminated in this context. If perceptual load was only acting on either sensory or physiological cues, a partial reduction in satiety response would have been expected. However, it should also be noted that memory ratings of the difference in ‘creaminess’ of the two preload drinks were not affected by perceptual load. Therefore, this suggests participants had some awareness of the sensory difference but were unable to integrate this information with internal physiological control of appetite at the time of consumption. We note that for consistency with previous studies (e.g., McCrickerd et al., 2014; Bertenshaw, Lluich & Yeomans, 2013) a sensory rating of ‘thickness’ may have also been useful. However, the fact that perceptual load did not impact awareness of LE/HE differences in pleasantness, sweetness and creaminess, and in particular that the creaminess LE/HE difference was noticed irrespective of load, makes it unlikely that our key findings were in any way impacted by load effects on awareness of the LE/HE thickness difference. Future research could adapt our paradigm to isolate the effect of perceptual load on sensory and physiological cues, by using a more subtle preload based only on one of these factors.

Our findings build on existing models of appetite control, such as the satiety cascade (Bellisle & Blundell, 2013; Blundell & Tremblay, 1995), which have increasingly allowed for cognitive influences on satiety. However, these influences have been suggested to operate at early stages of ingestion as modulators of post-ingestive nutrient based satiety. For example, Rolls, Bell and Waugh (2000) found that doubling the perceived volume of a

milkshake preload reduced subsequent intake by 12%, suggesting that cognition was having a moderate impact on satiety, but did not override later physiological aspects of ingestion (i.e., the actual energy content of the preloads). In contrast, our experiment found that the satiety response was entirely eliminated by high perceptual load, suggesting that factors acting throughout the satiety cascade (such as post-ingestive nutrient-derived cues) are dependent on the availability of basic perceptual capacity. Therefore, the current findings support growing research emphasising the role of cognition in satiety (Higgs et al., 2017). They are also consistent with previous studies showing that attentionally demanding real-world tasks at the time of initial consumption increase subsequent intake (Higgs, 2015; Higgs & Woodward, 2009; Mittal et al., 2011; Oldham-Cooper et al., 2010; Robinson et al., 2013). By integrating a more direct perceptual load manipulation of attention with a controlled preload manipulation of satiety, our findings extend these earlier findings by demonstrating that, at least within the context of our design, the impact of a cognitive factor (attention) is not limited to decreasing satiety, but can in fact entirely eliminate the satiety response.

Based on our findings here, we propose that perceptual load may also disrupt the brain's ability to adequately integrate satiety signals in a manner that affects behaviour or awareness of internal states, despite the presence of nutrients in the gut accompanied by a congruent sensory cue. Perceptual load is known to substantially disrupt information processing from the earliest stages of perceptual processing to encoding into memory, indexed by both behavioural and neural measures (Lavie, 2005; 2010). As such, an important direction for future research could be to elucidate the precise mechanisms underlying the perceptual load effects observed here. One possibility is that perceptual load would reduce neural activity associated with satiety. For example, after eating to satiation,

previous research has found that activity in the hypothalamus and reward-related brain regions (nucleus accumbens, ventromedial prefrontal cortex and orbitofrontal cortex) was attenuated but activity in the dorsolateral prefrontal cortex was increased (Thomas et al., 2015). Future neuroimaging research could test whether neural activity associated with satiety is altered under high perceptual load (i.e., typical reduction or increase in neural activity does not occur), further elucidating the underlying attentional mechanism.

It should be acknowledged that these results have been obtained from a single experiment study conducted with a healthy-weight, female and predominately student sample. A vital next step is, of course, to replicate this finding in wider samples, considering individual differences in eating behaviour. Keeping these limitations in mind, the results could have substantial potential implications for both research and healthcare. Firstly, the effect of distraction on subsequent intake has been argued to influence intake via a variety of mechanisms (such as mood and reduced memory), while the current findings suggest that increased intake can also occur due to a basic lack of perceptual resources. Secondly, Load Theory argues that perceptual load has a distinct effect on attentional processing by exhausting capacity and filtering out non-task stimuli in a passive manner (in this situation, satiety signals), whereas other forms of task load, such as cognitive demand, have the opposite effect on attentional processing and instead tax cognitive control resources. Establishing a role of perceptual capacity in existing theory will allow predictions over real world eating behaviour to be more specific about the nature of attention and future research to be mindful of processing limits.

The knowledge that satiety, one of the most important determinants of intake, is strongly affected by availability of attentional capacity could help to inform cognitive dietary interventions. Our findings suggest the focus of such interventions should be on

ensuring attentional capacity remains available for the duration of ingestion and the subsequent period, as cognition is a key component of regulating intake. Therefore, tasks which may involve high perceptual demand, such as television and video games, should be avoided when consuming food. Our results might also suggest that perceptual load particularly affects physiological components of satiety, as participants still remembered some sensory differences in the preload beverages (although a more direct test of sensory and physiological factors is required).

To summarise, our study shows that perceptual load strongly disrupts the satiety response to a high energy, thick texture preload beverage. This supports recent cognitive models of satiety, suggesting that accurate appetite control requires attentional resources to be available. Load Theory may be a useful framework from which to predict intake and subjective appetite. Practically, it may be a useful recommendation to avoid high perceptual tasks, and potentially, the success of cognitive dietary interventions could be affected by whether participants are able to pay attention to the processing of satiety-related information.

5.5. Supplementary information

Table S1

Mean individual characteristics (SE in parentheses) across each experimental condition

	Low perceptual load		High perceptual load	
	Low energy	High energy	Low energy	High energy
	preload	preload	preload	preload
Restraint	10.30 (.62)	8.33 (.62)	8.17 (.80)	8.93 (.73)
Disinhibition	7.33 (.52)	7.50 (.55)	6.37 (.53)	7.27 (.54)
Sensitivity to reward	10.50 (.67)	11.90 (.66)	12.70 (.69)	11.53 (.81)
External eating	3.29 (.09)	3.36 (.10)	3.18 (.07)	3.34 (.11)
Body Mass Index	23.21 (.61)	22.89 (.65)	23.14 (.77)	22.40 (.81)

Note: Disinhibition = Three factor eating questionnaire, disinhibition subscale; Restraint = Three factor eating questionnaire, restraint subscale; Sensitivity to reward = Sensitivity to punishment and reward Questionnaire, reward subscale; External eating = Dutch Eating Behaviour Questionnaire, external eating subscale.

Table S2.

Unadjusted 2 x 2 ANOVA model for the effect of preload and perceptual load on intake.

Follow up t-tests are reported under each level of perceptual load.

Unadjusted	df	<i>F</i>	<i>p</i>	N_P^2
ANCOVA model				
Preload	1, 116	6.26	.014	.05
Perceptual load	1, 116	.09	.770	.00
Interaction	1, 116	11.14	.001	.09
Follow up t-tests	df	<i>t</i>	<i>p</i>	<i>d</i>
Low perceptual load	58	4.32	<.001	1.13
High perceptual load	58	.57	.573	.15

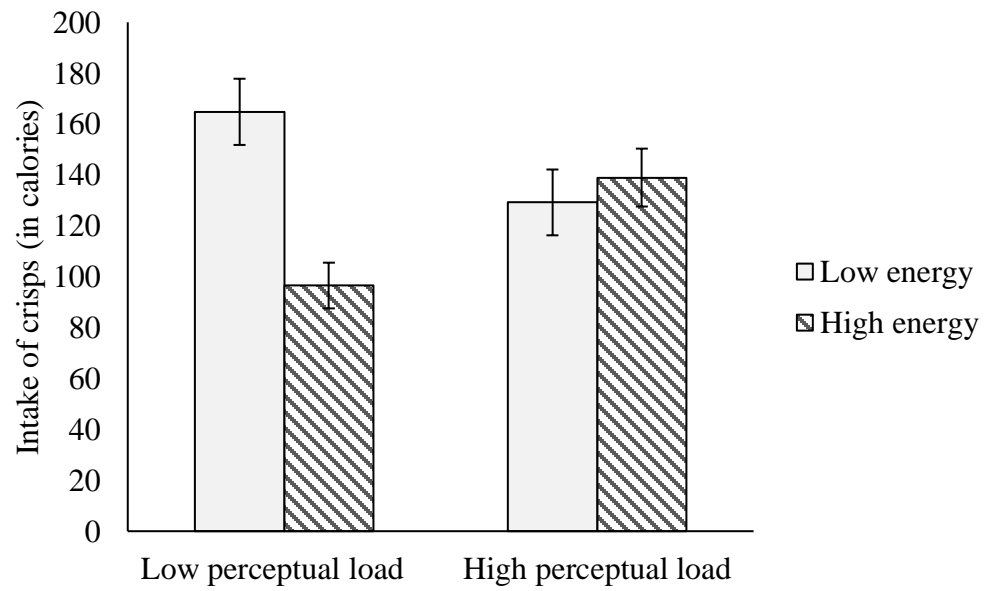


Figure S1. Unadjusted mean calorie intake (\pm SEM) of crisps after consumption of LE or HE preload under low or high perceptual load.

Table S3.

Unadjusted 2 x 2 ANCOVA model for the effect of preload and perceptual load on change in experienced satiety. Follow up ANCOVA's are reported under each level of perceptual load.

Level of perceptual load	Effect	df	<i>F</i>	<i>p</i>	N_p^2
-	Baseline satiety	1, 115	16.66	< .001	.13
-	Preload	1, 115	.42	.520	.00
-	Perceptual load	1, 115	.19	.664	.00
-	Interaction	1, 115	8.18	.005	.07
Follow up tests					
Low load	Baseline satiety	1, 57	6.21	.016	.10
	Preload	1, 57	6.28	.015	.10
High load	Baseline satiety	1, 57	10.70	.002	.16
	Preload	1, 57	2.36	.130	.04

Note: the models reported above have not been adjusted for covariates relating to individual differences. However, it is important to include baseline satiety for accurate interpretation (Blundell et al., 2010), and therefore this variable has been retained in analysis.

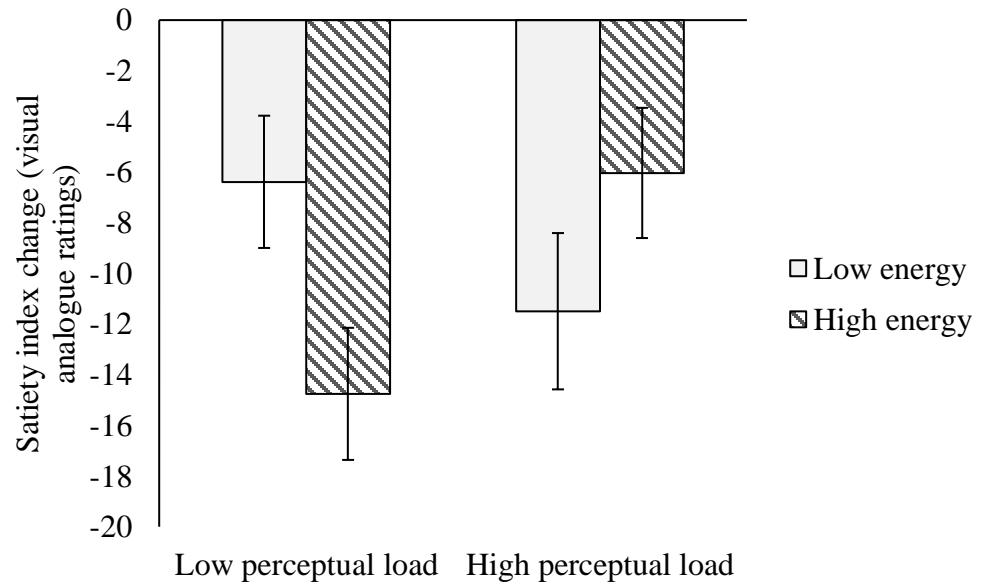


Figure S2. Overall unadjusted satiety index change after consumption of LE or HE preload under low or high perceptual load. A larger negative score reflects a greater increase in experienced satiety.

6. General Discussion

6.1. Aims of thesis

This thesis tested a perceptual load theory framework of eating behaviour. The research presented in the introduction to this thesis outlined the role of attention in a variety of eating-related behaviours, including the processing of external and internal food-related cues both prior to consumption and during/post consumption processes such as flavour awareness and satiety. However, ‘attention’ has often been broadly defined in studies intending to manipulate its effect (see section 1.4). Most commonly, attention has been viewed as a unitary process, and advances within the attention literature have not been utilised. The overarching question of this thesis was whether a perceptual load theory framework could be used to predict multiple aspects of eating behaviour. To answer this question, several key parameters needed to be established. Firstly, whether perceptual load modulated processing of food stimuli within an established paradigm: the visual search task. Previous research has suggested that some stimuli categories, such as those associated with reward (e.g., monetary reward, happy faces and erotic stimuli), are immune to the effect of perceptual load (Gupta, Hur & Lavie, 2016). Therefore, this raised the possibility that food stimuli, due to its rewarding association with the effects of ingestion such as sensory experience and post-ingestive effects of nutrients (Anderson, 2016; Berridge, 2009; Robinson & Berridge, 2001), would also carry a ‘special’ status reflected by immunity to perceptual load. Secondly, whether perceptual load affected intake. While distraction tasks have been previously used to study eating behaviour, no previous studies have involved a perceptual load manipulation (section 1.4). This second test also represented an advance in perceptual load theory, as few studies have applied the predictions of the theory to a real-

world applied context. Finally, as an additional aim, we tested whether individual characteristics related to eating behaviour interacted with the effect of perceptual load. The following sections (6.1.1 – 6.1.3) will summarise the main thesis findings in relation to the research questions outlined above.

6.1.1. Does perceptual load modulate processing of food stimuli within established paradigms?

Papers 1 and 2 tested the effect of perceptual load on the processing of food stimuli in a paradigm already established within the perceptual load theory literature. Paper 1 involved three experiments focusing on external distraction. The visual search task used in these experiments has been widely used throughout the perceptual load theory literature and has been known to reduce distractor processing of a range of salient distractor categories (e.g., Bishop, Jenkins, & Lawrence, 2007; Forster & Lavie, 2008; Yates, Ashwin, & Fox, 2010). Across all three experiments, perceptual load reduced distractor interference from food stimuli in the same manner as non-food stimuli (an attentional bias was not found), even when food stimuli were pre-rated to be more positive and higher in arousal than the non-food control category. This clarified that food stimuli were not subject to any special attentional status with respect to perceptual load modulation. Therefore, these experiments provided initial support for a perceptual load theory framework of food-related cognition. A memory bias was also observed for food stimuli across all three experiments. Crucially, in Experiment 3, high perceptual load reduced recall of both food and non-food stimuli. In addition, increased memory for food stimuli did not appear to be related to increased attentional processing, suggesting attention and memory processes are dissociable in this context. While perceptual load theory has focused primarily on attentional processing,

subsequent processes such as memory have also been shown to be affected by high perceptual load (Jenkins, Lavie, & Driver, 2005). Therefore, our findings regarding memory further support the use of perceptual load theory as a comprehensive framework of food-related cognition, extending beyond attentional effects.

In a similar design, we obtained evidence for perceptual load modulation of internal distraction by food. Paper 2 used the visual search task, which had previously been adapted to measure task unrelated thoughts (Forster & Lavie, 2009). Appetitive-related thoughts were clearly reduced when participants completed the high perceptual load task. This was the first time perceptual load had been used to reduce processing of a salient internal stimulus such as food. Furthermore appetitive-related thoughts were reduced on varying levels of meta-awareness (self-caught and probe-caught), although the perceptual load effect was larger on the self-caught measure.

In summary, the first set of experiments confirmed that both internal and external distraction by food can be reliably and powerfully reduced by perceptual load. This was a vital aspect of the framework to establish. If food-related cues had been immune to the effect of perceptual load, then it may have suggested that perceptual load theory was not applicable to the study of eating behaviour.

6.1.2. Does perceptual load modulate intake?

Papers 3 and 4 incorporated the visual search manipulation of perceptual load into paradigms previously used to manipulate intake. Paper 3 used a palatability manipulation, where participants were expected to consume more palatable compared to unpalatable food. I expected participants to show less awareness of this flavour contrast under high compared

to low perceptual load, demonstrated by a more similar intake of both food types when engaged in the high perceptual load task. However, in two experiments, there was no evidence that this was the case. Perceptual load did not modulate flavour awareness of snack foods, even when the task was made hands free (to encourage higher intake and increase the likelihood of observing a difference) or in comparison to a ‘no load’ control condition. As this was the first application of perceptual load theory to eating behaviour, it raised the possibility that the task was unsuitable. However, in Experiment 3 participants consumed less food (overall) in the control condition compared to both low and high perceptual load conditions. Therefore, the paradigm was able to detect a typical inattentive eating effect and should have been able to find a load effect on flavour awareness. Instead, this null result may reflect a potential exception to perceptual load theory.

In contrast, there was strong evidence that perceptual load modulated eating behaviour in Paper 4, where the visual search task was integrated into a preload design. Our results found that when engaged in the low perceptual load task, participants demonstrated typical compensatory behaviour (reduced appetite in response to a high compared to low energy beverage). However, participants could not exert satiety-based control over appetite when engaged in the high perceptual load task. This was found on both objective intake and subjective self-reported experienced satiety ratings. This finding further suggested that the lack of perceptual load modulation on flavour awareness in Paper 3 did not mean perceptual load theory could not be applied to study eating behaviour. Furthermore, Paper 4 suggests that the effect of perceptual load is not limited to immediate intake but has a more powerful effect upon subsequent consumption. This is in line with previous research, which

has suggested that distraction has a larger impact on subsequent compared to immediate intake (Robinson et al., 2013).

6.1.3. Do individual differences in eating-related characteristics interact with perceptual load?

Papers 1 and 2 used within subject designs with large samples. Therefore, there was greater scope to investigate individual differences within these two papers. It was not possible to incorporate both low and high perceptual load into the same task in Papers 3 and 4 and using a within subject design over multiple days would have made it difficult to disguise the purpose of the experiments. Therefore, in order to prioritise our primary research questions, between subject designs were used in Papers 3 and 4. This reduced experimental power to investigate individual differences (Faul, Erdfelder, Lang, & Buchner, 2007). Instead, individual differences were included in Papers 3 and 4 for control purposes—there were no group differences on any of the measures used and so individual differences were not included in further analyses.

In Paper 1, we found no consistent relationships between individual traits and any measures of attentional processing (attentional capture or bias). This area of investigation may have been partly limited by our lack of overall attentional bias for food cues. However, we did find a consistent relationship between memory for food cues and trait disinhibition (TFEQ) in all three experiments. BMI also correlated with memory for food cues in Experiments 1 and 2 (although the non-significant relationship in Experiment 3 may have been caused by a switch to a less reliable self-report measure of BMI). In Experiment 3 only, we were able to isolate memory under low and high perceptual load. Disinhibition correlated specifically with memory for food cues presented under high perceptual load.

Therefore, some traits related to eating behaviour may persist even under high perceptual load. However, this relationship was observed in only one experiment and therefore should be interpreted with caution (due to the risk of false positives from over testing).

In Paper 2, we observed no trait differences in eating behaviour related to the number of appetitive-related thoughts under either level of perceptual load. However, several state differences were seen under low perceptual load: hunger, chocolate specific craving and chocolate specific liking were all significantly related to increased frequency of appetitive-related thoughts. Under high perceptual load, these relationships were all eliminated. Thereby suggesting that perceptual load modulated internal distraction by food across all individuals.

To summarise, trait differences were not consistently related to external or internal attentional processing of food under low perceptual load. In Paper 1 there was tentative evidence that disinhibition might be related to memory for food cues, even under high perceptual load. Therefore, this suggests there might be some interaction between individual processing and perceptual load. However, in Paper 2, perceptual load powerfully reduced all state differences seen under low perceptual load. The relationship between individual differences and perceptual load varied between studies, and therefore may be dependent on context (e.g., external vs. internal distraction).

6.1.4. Can perceptual load theory be used as a framework of eating behaviour?

To summarise, we have identified that perceptual load modulates several aspects of eating behaviour, including behaviours prior to consumption and those which influence intake during and after consumption. Therefore, the findings presented throughout the four

papers suggest that perceptual load theory can be used as a framework of eating behaviour, as predictions about processing and behaviour can be made depending on whether an individual is engaged in a low or high perceptual load task. Predictions regarding individual differences are somewhat limited due to a lack of trait variation under low perceptual load. The current thesis did not test the second prediction of perceptual load theory: that cognitive load increases processing of irrelevant stimuli. However, previous eating behaviour research has found that cognitive load tasks increase intake and implied processing of food-related information (Mann & Ward, 2004; Zimmerman & Shimoga, 2014). In addition, the role of working memory (which cognitive load is known to tax) has been well documented in relation to food processing and consumption (Higgs & Spetter, 2018). Therefore, previous research is compatible with the latter aspects of perceptual load theory (see section 1.5.2), and supports our proposed use of perceptual load theory as a cohesive framework of eating behaviour.

6.2. Implications

There are several key implications for both the eating behaviour and attention literatures. I will first discuss implications for the eating behaviour literature, as utilising theoretical advances from the attention literature was the key aim of this thesis. However, the application of perceptual load theory in the novel context of eating behaviour also has significant implications for the attention literature, which will be discussed separately.

6.2.1. Implications for the eating behaviour literature

The key implication from this thesis is that several aspects of food-related processing can be affected by perceptual load. Within the perceptual load theory

framework, I have argued that attention has a different impact on eating behaviour depending on stage of consumption. Namely, that attention towards food prior to consumption, but a lack of attention towards food during and post consumption both increase the risk of over-eating. As has been outlined in detail in Section 1.3, prior to consumption, external and internal food-related cues have been argued to influence intake via a mutually excitatory relationship with craving (Field & Cox, 2008). However, crucially, papers 1-2 demonstrated that attentional processing of food-related cues only occurred in perceptually undemanding situations. Therefore, the opportunity for those cues to influence intake should also be limited to perceptually undemanding situations. This also implies that individuals who experience high perceptual demands in their everyday life (e.g., working with busy spreadsheets) may be less affected by food-related cues in their environment. In contrast, during and post consumption, lack of attention (due to distraction) to food has been argued to influence intake via a variety of mechanisms including reduced self-monitoring and breakdown of restraint (Section 1.4.2: For example, Mann & Ward, 2004; Ward & Mann, 2000). However, paper 4 suggested, for the first time, that increased intake could be caused by a basic lack of perceptual resources available to process internal satiety signals. This suggests that perceptual load theory can be effectively applied to processing of interoceptive as well as external signals, and that reduced attention (due to exhausted perceptual capacity) for processing internal satiety cues could lead to short-term appetite disruption. Therefore, individuals who frequently consume food while engaging in high perceptual load tasks (e.g., while working at their desk or watching television) are likely to be less able to adjust their subsequent intake in response to these missed satiety cues. To summarise, three aspects of eating behaviour (attention to external cues, internal cues and internal satiety signals) have been shown to be dependent on perceptual capacity

limits. Therefore, the perceptual load framework suggested in this thesis has implications for real world eating behaviour.

As this was the first test of perceptual load in the context of eating behaviour, theories in the eating behaviour literature have not allowed for a role of perceptual capacity. However, as processing limits based on perceptual capacity are largely predictable and reliable (Lavie, 2010; Lavie, Hirst, de Fockert, & Viding, 2004; Murphy, Groeger, & Greene, 2016), they have implications for and can be incorporated into existing theory. There are several theories detailing the role of attention in eating behaviour prior to consumption (see section 1.3)—the elaborated intrusion theory (Kavanagh, Andrade, & May, 2005; May, Andrade, Kavanagh, & Hetherington, 2012) considers the role of both external and internal food-related cues, and suggests that craving for food can be reduced by visually demanding tasks, implying that processing capacity is limited (albeit in relation to visual imagery). This aspect of the model could be further specified by outlining the role of perceptual capacity. In terms of appetite control, the satiety cascade has been one of the most influential psychological models (Blundell et al., 2010; Blundell, 1991; Mela, 2006). In this model, cognitive factors are argued to influence intake, but only at early stages of ingestion. Our findings from paper 4 suggest a stronger role of cognition: if attentional resources are not available, then combined physiological and sensory cues cannot exert control over satiety. Establishing a role of perceptual capacity in existing theory will allow predictions over real world eating behaviour to be more specific and future research to be mindful of processing limits.

The findings from this thesis support more recent cognitive models of eating behaviour, such as those described by Davidson et al (2014; 2019) and Higgs & Spetter

(2018). These models suggest that memory plays an important role in appetite control by guiding attention towards food cues prior to consumption, allowing attention to be paid to food when eating, and providing information about recent eating episodes at later timepoints. While it has been assumed that memory effects occur via changes in attention, there has been limited evidence that this is the case, as previous studies have tended to use either working memory tasks (e.g., digit span) or television as a manipulation (the issues with which have been previously discussed in Section 1.4). This thesis builds upon this work by using a manipulation where the effects on attention are known, providing a more direct test of attention. Furthermore, previous cognitive models have often focused on the effects of working memory on intake, which perceptual load has been previously found not to tax and when directly compared produces opposite effects (perceptual load reduces whereas working memory/cognitive load increases attentional processing: Lavie et al, 2004). Therefore, this thesis has identified a novel perceptual mechanism that influences multiple aspects of eating behaviour.

Perceptual load theory further specifies how the attentional mechanism operates, by suggesting that when attention is not available, food-related cues and satiety-related information are filtered out at the earliest stage of perception. The vicious cycle model (Davidson et al., 2014, 2019) suggests the food and food-related stimuli are associated with positive and negative post-ingestive consequences. This information is stored in the hippocampus, which is known to subsequently guide attention (Goldfarb, Chun & Phelps, 2016). Food-related processing and decision making then depends on which association is most strongly activated in any given situation. Perceptual load may prevent these associations from occurring (perceptual load has been previously found to reduce activation

of associated stimuli: Lavie & Fox, 2000; Murphy, van Velzen & de Fockert, 2012). This could be useful to reduce activation of positive post-ingestive consequences (such as eating enjoyment), and therefore avoid reliance on effortful cognitive control systems to resist tempting food (which has been noted as a challenge of breaking the ‘vicious cycle’). However, this could also result in habitual eating due to associations with negative post-ingestive consequences not being activated (i.e., the feeling of being full at the end of a meal) – particularly if eating has already begun. High perceptual load during intake could also contribute to poor memory representations of the meal, resulting in increased subsequent intake (Higgs & Spetter, 2018), which further contributes to the impaired hippocampal function and cognitive control described by the vicious cycle model (Davidson et al., 2014; 2019). The application of perceptual load theory in this area can further specify the role of attention, and how the process of inattentive eating might occur.

Establishing parameters of cognitive processing are also useful for identifying aspects of eating behaviour that don’t appear to fit within the framework. In Paper 3, flavour awareness was not modulated by perceptual load, and this did not appear to be due to methodological issues (although further testing is needed to clarify this finding – see paper 3 for discussion). However, if flavour awareness is immune to the effects of perceptual load, this finding implies that some aspects of eating behaviour may operate outside of basic processing limits. This finding is important as it conflicts with previous research which has suggested that distraction may interfere with both flavour perception and sensory specific satiety (Braude & Stevenson, 2014; van der Wal & van Dillen, 2013—see section 1.4.3) and suggests the mechanism of these effects is something other than a purely attentional explanation (e.g., mood). It also has implications for inattentive eating, as

people may always be aware of food flavour. Therefore, while distraction may reduce awareness of satiety (paper 4), if intake is not a concern (e.g., someone of a healthy weight or trying to gain weight) then it may be less important to avoid distracting activities while eating. As discussed in paper 3, a number of attentive-eating interventions, which involve focusing on the sensory properties of food (such as flavour), have been found to be ineffective (Whitelock, Gaglione, Davies-Owen, & Robinson, 2019; Whitelock, Higgs, Brunstrom, Halford, & Robinson, 2018). Our results support the idea that attentive eating interventions which focus on sensory aspects of food may be ineffective (as flavour processing may not be dependent on attentional resources) and imply that interventions should instead focus on emphasising satiety.

A further implication for the eating behaviour literature is that attention is not a unitary construct. This knowledge has important methodological implications for studies manipulating the effect of attention. For example, high perceptual demand may mask biased attention in studies attempting to observe an effect. If a proposed study is attempting to observe an attentional bias—for example, if the study is investigating individual differences in the bias—then high perceptual load would be an unwanted confound. Therefore, such studies should ensure that the task used is low in perceptual load. It has been suggested that some tasks, such as the rapid serial visual presentation task, may theoretically be high in perceptual demand as they involve searching for a target image among a stream of rapidly presented images (Brown, 2018). In addition, when perceptual load has specifically been manipulated in a rapid serial visual presentation task, high perceptual load has reduced attentional bias on this task (Elliott & Giesbrecht, 2010; Stein, Peelen, Funk, & Seidl, 2010). Several studies using the rapid serial visual presentation task

have failed to find evidence of biased attention towards food stimuli across a general sample (e.g., Neimeijer, de Jong, & Roefs, 2013; Piech, Pastorino, & Zald, 2010). Note that Paper 1 found no evidence of attentional bias under low perceptual load, and therefore other failures to observe attentional bias for food stimuli are not necessarily due to accidental high perceptual demand in the task. However, now that this thesis has established that food-related stimuli are modulated by perceptual load, future studies can better control for this potential confound.

In contrast, there may be situations in which comparing differences in processing under low and high perceptual load may be interesting to the research question. Establishing parameters of basic processing means that any exceptions to the effect of high perceptual load can be identified. Paper 1 found a relationship between trait disinhibition and increased recognition accuracy for food images, even under high perceptual load. Therefore, the implication is that food-related cues will always receive prioritised processing in some individuals. As will be discussed in section 6.3, the perceptual load task could be used to identify individuals who are susceptible to the impact of food-related cues in their environment, and therefore create tailored recommendations for appetite management.

Awareness that attention is not a unitary construct also has implications for intake studies. It may be particularly important to control task load in situations where the behavioural outcome may be the same. For example, inattentive eating could arise from either high perceptual or cognitive load. In Paper 4, high perceptual load increased intake at a later timepoint compared to low perceptual load. As cognitive load was controlled for in these experiments, the likely cause of the increased intake can be attributed to perceptual

load. However, as has been reviewed in section 1.5.2, cognitive load (as defined by perceptual load theory) is likely to tax cognitive control resources and disinhibit healthy eating goals—meaning that both perceptual and cognitive load could result in inattentive eating. Previous research investigating the mechanisms of inattentive eating may have confounded perceptual and cognitive load (e.g., Higgs, 2015a—as discussed in section 1.5.3). Therefore, both perceptual and cognitive load would potentially result in inattentive eating, but the underlying mechanisms would be different.

6.2.2. Theoretical implications for the attention literature

The studies presented have several important implications for the attention literature. Crucially, that food does not represent a category which receives enhanced processing above and beyond non-food stimuli in regard to perceptual load. Within the attention literature, it has frequently been suggested that rewarding stimuli may receive preferential attention (Anderson, 2016; Watson, Pearson, Wiers, & Le Pelley, 2019). However, across Papers 1-2, high perceptual load reduced processing of external and internal food-related cues, further supporting the role of perceptual load as a powerful and robust determinant of selective attention, even when stimuli are highly salient and rewarding (Anderson, 2016; Berridge, 2009).

This finding also adds to the debate on whether certain categories, including rewarding stimuli, are ‘immune’ to the effects of perceptual load (Gupta, Hur, & Lavie, 2016). The findings from Paper 1 suggest that this ‘immunity’ effect for rewarding stimuli may not generalise beyond the specific categories (happy faces, erotic images and money associated stimuli) identified by Gupta, Hur & Lavie (2016). However, differing conclusions regarding ‘immunity’ effects could also be due to methodological differences.

The stimuli used by Gupta, Hur & Lavie (2016) were presented at fixation and were significantly larger than the fixation stimuli used in Paper 1 (at least three times larger vertically and six times larger horizontally). Therefore, these stimuli may have been more distracting – in support of this, distractor costs were also larger than in Paper 1 (under low perceptual load, these ranged from approximately 65 – 140 ms compared to 31 – 35 ms in the Paper 1 fixation experiments). This raises the possibility that immunity to perceptual load may only be observed when distractor interference is particularly high. However, immunity effects have been found in several studies using stimuli of comparable sizes (3 – 5 degrees at periphery) to the experiments in this thesis (Lavie, Ro, & Russell, 2003; He & Chen, 2009; Ro, Friggel & Lavie, 2009). Therefore, large stimuli sizes do not appear necessary to capture immunity effects. In addition, if immunity effects can only be observed in ideal conditions then it is unlikely to be a reliable phenomenon, particularly in the real world where food cues may not be presented in such an attention grabbing manner (i.e., not at fixation and while competing for attention among other distracting stimuli). Therefore, the studies in this thesis suggest that food cues do not hold a ‘special’ status in perceptual processing and are subject to perceptual capacity limitations.

The finding that food stimuli were modulated in the manner predicted suggests that perceptual load theory can be extended to the study of food-related processing. This implies that other aspects of perceptual load theory would also be expected to modulate processing of food cues. For example, high cognitive load has been found to increase processing of irrelevant stimuli (Lavie et al., 2004) and therefore the same effect would be predicted with food cues. More importantly, perceptual load theory can be extended to study complex behaviours, as Paper 4 established that both intake and subjective appetite were modulated

by perceptual load. Greene & Murphy (2016) emphasised that applying perceptual load theory to real world scenarios was a crucial next step in the development of the theory, as the theory makes many predictions about real world behaviour but evidence testing those predictions is lacking. Furthermore, some attention paradigms, such as the Posner cueing paradigm, have been criticised for being overly focused on theoretical predictions derived from artificial tasks (Kingstone, Smilek, Ristic, Kelland Friesen, & Eastwood, 2003). In the Posner cueing paradigm (Posner, 1978), spatial attention to a target stimulus (which appears on the left or right of a display) is cued by the orientation of an irrelevant arrow stimuli (i.e., if the arrow is pointing left, then the participant should attend to the left location), but this effect is only observed when the arrow is informative (i.e., correctly predicts the location of the target on a majority of trials). It was therefore suggested that individuals had voluntary control over shifts in spatial attention. However, Friesen and Kingstone (1998) found that a real world spatial orienting cue (eye gaze direction instead of arrow orientation) influenced spatial attention, even when non-informative. Therefore, a small change in the task revealed that theoretical predictions may not accurately reflect attention in a more ecologically valid setting. Perceptual load theory had previously been shown to influence driving behaviour and eyewitness testimony. This thesis further builds upon this evidence to show that perceptual load can and does impact behavioural outcomes beyond the distractor interference measured in the original task.

There have been mixed findings as to whether perceptual load can act cross-modally. In this thesis, evidence was also conflicting. In Paper 3, there was no evidence that perceptual load reduced flavour awareness. One potential explanation was that the palatability manipulation (salted vs unsalted crisps) in Paper 3 was too strong. Potentially a

subtler flavour manipulation would be modulated by perceptual load. Alternatively, the results could imply that there is something unique about flavour perception that warrants further study (see Paper 3 for further discussion). It should also be noted that flavour involves multiple senses such as taste, smell and mouthfeel, which may lower the threshold for awareness, making it more difficult to eliminate with perceptual load. Most perceptual load theory research has focused on the ability of perceptual load to reduce processing in one other modality (e.g., Forster & Spence, 2018; Macdonald & Lavie, 2011; Murphy & Dalton, 2016). Therefore, a complex multisensory experience such as flavour may be immune to the effect of perceptual load and instead suggest a parameter for perceptual load theory. In contrast, Paper 4 perceptual load completely eliminated awareness of internal satiety signals. This was the first time perceptual load has been shown to modulate this type of sensory processing. Therefore, the implications from this thesis in terms of cross-modal effects of perceptual load are mixed, and instead highlight this area for future research.

6.3. Application of current findings

Given the negative health consequences of being overweight or obese (World Health Organization, 2017), much of cognitive eating behaviour research has focused on the reduction of over-eating (Higgs & Spetter, 2018; Jansen, Houben, & Roefs, 2015; Werthmann, Jansen, & Roefs, 2015). Therefore, a clear application of the findings from this thesis is in identifying situations where it is helpful or unhelpful to engage in perceptually demanding tasks to reduce over-eating. Prior to consumption, having attention available to process external and internal food-related stimuli is likely to have a negative impact on over-eating (as discussed in section 6.2.1). Therefore, purposefully engaging in perceptually demanding tasks may be a worthwhile tactic for those trying to avoid over-

eating (e.g., individuals on a diet). As has been discussed in papers 1-2, perceptual load powerfully and passively filters out task-irrelevant stimuli, and therefore may be advantageous over craving-reduction techniques that require time and effort or maintenance of cognitive control (see sections 1.3.3 and 1.3.4). Instead, individuals can try to organise perceptually demanding tasks during periods when they might be susceptible to snacking (e.g., positive evaluation of unhealthy snack foods has been found to be higher in the afternoon period between lunch and dinner, Haynes, Kemps, & Moffitt, 2016). However, once the individual has started to eat, the opposite advice should be given. Paper 4 emphasised that high perceptual demand particularly impacted the ability of internal satiety signals to control subsequent consumption, whereas paper 3 found no impact of perceptual load on flavour awareness. Therefore, advice should focus on avoiding perceptually demanding tasks both during consumption and the subsequent period, so that attention is fully available to process internal satiety cues. In contrast, the opposite advice could be given to those trying to increase their food consumption. For example, elderly people frequently report low appetite (Pilgrim, Robinson, Sayer, & Roberts, 2015). Reducing awareness of satiety signals by eating while simultaneously engaged in a task could help increase subsequent consumption.

An advantage of perceptual load is that manipulations are naturally occurring and present in everyday life (Murphy et al., 2016). This means that high perceptual load can be found in common tasks (e.g., reading a book with a smaller font) and therefore individuals are able to incorporate high perceptual load into their existing activities, rather than engaging in a specific perceptual load manipulation (e.g., visual search task). Sometimes the low vs high perceptual load distinction may be intuitive to notice and therefore easy for

an individual to manipulate. For example, the difference between walking down a busy, cluttered street compared to a quiet empty one is fairly clear. However, the relative level of perceptual and cognitive demand in other tasks may be more ambiguous, and perceptual load theory has been criticised for the lack of empirical research testing naturalistic manipulations of perceptual load (Furley, Memmert, & Schmid, 2013; Murphy et al., 2016). For example, I have suggested in this thesis that television is likely to be a high perceptual load task. However, the precise level of perceptual demand is likely to vary. For example, watching Countdown (a television show which involves word and number games) may involve higher cognitive than perceptual demand, but watching Blue Planet (a nature documentary) may involve higher perceptual demands. Hopefully, as perceptual load theory research continues, more real world manipulations of perceptual load will be identified.

As we found little evidence for individual differences influencing eating-related behaviour under high perceptual load, recommendations could be aimed at the general population. This simplifies potential advice, which may make it more achievable to follow (complex health and weight-loss advice has been cited as a barrier to dieting success, Buchanan & Sheffield, 2017). However, one exception was the relationship between disinhibition and memory recall of food stimuli under high perceptual load in Paper 1. Presumably, these individuals would always have better memory for food cues despite engaging in high perceptual load tasks, undermining the purpose of the task. Some studies have shown that a high enough level of perceptual load will exhaust attentional capacity in all individuals (e.g., Remington, Swettenham, Campbell, & Coleman, 2009). Therefore,

one potential solution is to try and choose tasks that are particularly high in perceptual load. However, it is difficult to judge the precise level of perceptual load in real world tasks.

Exceptions to the perceptual load framework (individuals who still process food under high perceptual load), could prove useful in building a ‘cognitive profile’ for that individual. Understanding why some individuals overeat while others do not has been a core question in obesity research (Werthmann et al., 2015). It has been argued that unhealthy eating habits can be targeted by interventions that tackle the underlying cognitive mechanisms, such as attentional bias retraining (Jansen et al., 2015). Identifying individuals who prioritise food, even when basic perceptual limitations should eliminate processing, may help to inform interventions. Alternatively, such individuals may be resistant to interventions, and therefore a more useful approach could be to identify situations in which they will be especially vulnerable to over-eating. This would instead allow them to avoid high-risk situations.

6.4. Limitations

One methodological consideration which applied to all of the research conducted for this thesis is the biased sample. Participants were all highly educated (primarily University of Sussex students), young, of a healthy-weight and female. Educational status and BMI were due to practical constraints of available participants. Age and Gender were intentionally controlled. Due to age-related decline in visual processing, the subject pool was restricted to 18-35 year olds. The sample was restricted to female participants only because of the difficulty recruiting an equal number of men and women from a predominantly female cohort of students, and because men tend to approach intake experiments as an opportunity to consume as much food as possible (Mittal, Stevenson,

Oaten, & Miller, 2011). Similar to much of psychology research, it could be argued that our findings do not represent the general population (Hanel & Vione, 2016). In particular, BMI may be a variable that interacts with the effect of perceptual load, yet we tested a healthy-weight sample. However, as this was the first application of perceptual load theory to eating behaviour, it was important to first establish whether food would be modulated by perceptual load. We made an effort to measure potential individual difference variables, however, ensuring that the perceptual load theory framework was applicable across every population subgroup was beyond the scope of this thesis. Now that the effect of perceptual load has been established in several aspects of eating behaviour, future research can focus on extending these effects.

A further consideration is that all of the evidence gathered in our experiments were reliant on the visual search task. Paradigm specific research has been criticised for being overly focused on the empirical effect of that paradigm, rather than the overarching research question (Meiser, 2011). In addition, the visual search task has been criticised as the low and high perceptual load versions are not visually identical—leading to the suggestion that the increased number of non-target stimuli in the search display dilute distractor interference from the task-irrelevant distractor stimulus (Tsal & Benoni, 2014). However, the suggestion of ‘dilution’ effects have been disputed (Lavie & Torralbo, 2010) and there is a variety of evidence for perceptual load that involves manipulations with identical displays (e.g., Bahrami, Carmel, Walsh, Rees, & Lavie, 2008; Cartwright-Finch & Lavie, 2007; Lavie, Lin, Zokaei, & Thoma, 2009; Lavie & Torralbo, 2010). Furthermore, while the task remained constant in the studies conducted in papers 1-4, the dependent variable was not limited to distractor interference (which the dilution criticism is aimed at).

In addition, this reduced the issue of becoming overly focused on the empirical effect of a single paradigm, as effects of perceptual load were observed on distractor interference, recognition accuracy, self-reported thoughts, intake and subjective appetite ratings. While it may be interesting to use an alternative perceptual load paradigm in future research, keeping the task constant across the studies in papers 1-4 meant each study was comparable. Finally, as the majority of perceptual load research has used the visual search task, this meant our research was more closely aligned with the wider literature.

6.5. Future directions

The perceptual load theory framework suggested in this thesis was an initial test of whether the theory could be applied to eating behaviour, intended to create a clear framework from which to generate future research. Several areas of the framework could be expanded. The role of individual differences requires further study, due to the homogenous samples used in this thesis and the limited power to detect interactions in papers 3-4. It is still unknown whether perceptual load would modulate external and internal processing of food stimuli when strong individual differences have been induced, such as hunger after fasting. Given that attentional processing of food stimuli has been found to be stronger and more consistently observed in individuals who are hungry and/or overweight, this is a key question to answer in future studies (Castellanos et al., 2009; Hendrikse et al., 2015; Tapper, Pothos, & Lawrence, 2010; Werthmann et al., 2011). Paper 4 found, for the first time, that perceptual load completely eliminated ability to response to internal satiety signals. Given that some individuals, such as restrained eaters (e.g., Westenhoefer, Broeckmann, Münch, & Pudel, 1994), have been found to be more susceptible to over-eating in the preload paradigm used in paper 4, well-powered follow up studies

investigating this individual variation (and its interaction with perceptual load) would further expand upon this effect.

Paper 3 highlighted that there are exceptions to the perceptual load theory framework. Firstly, the reason for this exception should be clarified in future research—is flavour processing immune to the effect of perceptual load, or was this only observed in the specific studies conducted in paper 3 (see paper 3 for a more detailed discussion of this point)? As this may represent an exception to perceptual load modulation, it would be particularly interesting to test the effect of perceptual load on other aspects of eating behaviour not included in this thesis. As has been previously outlined (section 1.1.4), attentional processing has been implicated in a number of eating-related behaviours. For example, it has been suggested that level of attention paid to cues associated with sensory expectations (e.g., the label) influences sensory perception, hedonic appraisal and intake of food (for review see Piqueras-Fiszman & Spence, 2015). Perceptual load theory would predict that any aspect of eating behaviour which requires attentional processing should be reduced under high perceptual load. Returning to the example of sensory expectations, perceptual load research has shown that associations between an object and the appropriate action (e.g., grasping an object with a handle oriented to the right side with the right hand) did not occur under high perceptual load, suggesting that associations with stimuli could not occur when attention was not available. Therefore, potentially, it might also be expected that sensory expectations would not influence eating behaviour under high perceptual load. Further testing of perceptual load theory in the context of eating behaviour (such as the example described) would allow for a fully formed attentional framework of eating behaviour, able to predict a multitude of eating-related behaviours.

Several findings from the reported studies highlighted the potential of perceptual load theory to explain longer term aspects of eating behaviour. For example, Paper 4 demonstrated that inattention to satiety cues at the time of intake determined intake thirty minutes later. It would be useful, especially from a point of view of trying to predict real world behaviour, to increase the interval between preload and subsequent intake test. Potentially, if inattention at initial consumption filtered out satiety-related information, then intake could continue to be affected throughout the day. The finding would be in line with previous research, which has shown that distraction at the time of initial consumption can increase subsequent intake two and a half hours later (Higgs & Woodward, 2009). In addition, Paper 1 highlighted that perceptual load reduced memory for food cues. Future research could test whether enhanced memory for food cues increased subsequent craving and consumption during the day, and whether this is also dependent on level of perceptual load at exposure.

The interpretation of our results has relied upon behavioural outcomes. To some extent, predictions made from perceptual load theory can speculatively inform on the underlying mechanisms. For example, perceptual load reduces visual processing at an early stage in the visual cortex (Schwartz et al., 2005). It is therefore likely that the processing of external visual food stimuli was filtered out in a similar manner. However, Paper 4 applied perceptual load in a novel context, and therefore understanding of the underlying mechanisms is limited. Inferring from perceptual load theory, it seems likely that perceptual load interferes with the integration of the gut-derived satiety signal with the brain (as there is no theoretical reason to think perceptual load could affect physiological mechanisms of appetite control occurring outside the brain e.g., hormones). However, the study cannot

show exactly which neural mechanisms were affected by perceptual load. One possibility is that perceptual load would reduce neural activity associated with satiety. For example, after eating to satiation, previous research has found that activity in the hypothalamus and reward-related brain regions (nucleus accumbens, ventromedial prefrontal cortex and orbitofrontal cortex) was attenuated but activity in the dorsolateral prefrontal cortex was increased (Thomas et al., 2015). Another key structure in appetite control is the hippocampus, which is thought to be vital to the storage and integration of satiety signals in the brain (Davidson et al., 2019). The vicious cycle model suggests that this information is subsequently used by other ‘hippocampal-dependent’ neural regions, such as the prefrontal cortex, to inhibit intake. Future neuroimaging research could test whether neural activity in the hippocampus and other regions associated with satiety are altered under high perceptual load (i.e., typical reduction or increase in neural activity does not occur), further elucidating the underlying attentional mechanism

6.6. Final conclusions

In summary, the findings across this thesis suggest that perceptual load theory is a valid framework from which to study eating behaviour. Several aspects of eating behaviour were modulated by perceptual load including distraction, memory, intrusive thoughts and satiety. Preliminary findings regarding individual differences and potential exceptions to the perceptual load theory framework have highlighted areas for future research. Taken together, these results support my suggestion that the effect of attention on eating behaviour is dependent on stage of consumption: attention prior to consumption is likely to increase potential craving and intake, whereas the opposite is true during and after consumption. As discussed, the knowledge that attentional processing is dependent on perceptual capacity

limits has important implications for understanding previous eating behaviour research, informing future research and real-world applications. Finally, this thesis advances understanding of the role of attention in eating behaviour, suggesting for the first time, that perceptual load has a powerful effect on both food-related processing and consumption.

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